VAN NOSTRAND'S

ECLECTIC

ENGINEERING MAGAZINE.

NO. XCIII.—SEPTEMBER, 1876.—VOL XV.

ON THE THEORY AND CALCULATION OF CONTINUOUS BRIDGES.

By MANSFIELD MERRIMAN, C. E., Ph. D., Instructor of Civil Engineering in the Sheffield Scientific School.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE

II.

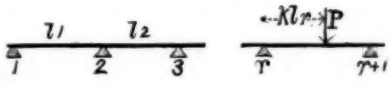
MOMENTS AT THE SUPPORTS.

The theorem of three moments given by (8) furnishes the means of finding the moments at the supports due to any assigned system of loading. The actual solution of those equations is, however, quite tedious when the number of spans is large, and we proceed therefore to develop a general solution, by which the values of the moments may be formulated and placed in a convenient form for numerical computation.

In the designing of continuous bridges it is only necessary to consider single loads concentrated at the panel apices or uniform loads extending over an entire span. Let us, then, consider a continuous girder of constant cross-section and homogeneous material whose supports are on the same level. Let, as in Fig. 6, the supports beginning at the left hand end be designated by the indices 1, 2, 3, ... r, etc, and the lengths of the spans l_1, l_2, l_3, ... l_r, etc. Call the number of spans s; then the last span will be l_s, and the last support $s+1$. The ends of the girders rest upon abutments in the usual manner, the lengths of the spans may be all different and their number may range from one to infinity.

In the span l_r let a single load P be placed at a distance $k\,l_r$ from the support r, (k being any fraction less than

FIG. 6.



unity), or let this span be loaded uniformly from r to $r+1$ with a weight W, (W being equal to $w\,l_r$, if w is the load per linear unit), all the other spans being unloaded. By reference to (8) we notice that there are two functions of such loads which enter the equations of moments. If the single load P is alone considered these functions are

$$P\,l_r^2\,(2\,k-3\,k^2+k^3)$$
$$P\,l_r^2\,(k-k^3)$$

the first entering into the equation for the preceding support r, and the second into the one for the following support $r+1$. If the uniform load over the whole span is alone considered, these become each equal to $\frac{1}{4}\,W\,l_r^2$, as we have shown above in discussing the theorem of three moments. In the following investigation, we place therefore for abbreviation

$$\left.\begin{array}{l} A = P\,l_r^2\,(2\,k - 3\,k^2 + k^3) \\ B = P\,l_r^2\,(k - k^2) \end{array}\right\} \text{for a single load in span } l_r.$$

(I)

$$\left.\begin{array}{l} A = \frac{1}{2}\,W\,l_r^2 \\ B = \frac{1}{4}\,W\,l_r^2 \end{array}\right\} \text{for a uniform load over whole span } l_r.$$

By introducing the letters A and B to represent these functions, our discussion will apply equally well to a single load P, or to a weight W uniformly distributed over the whole of a single span.

Since the girder is not fastened at the abutments 1 and $s+1$, the moments at those points will be zero. The moments at 2, 3, ... r, etc., we designate by M_2, M_3, ... M_r, etc., and from (8) we may write an equation for each of those supports. As there is no load considered except on the span l_r, the right hand member of the equation for the support r will be A, of that for $r+1$ will be B and of all the others will be zero. Thus we have the following equations:

$$2\,M_2\,(l_1+l_2) + M_3\,l_2 = 0$$
$$M_2\,l_2 + 2\,M_3\,(l_2+l_3) + M_4\,l_3 = 0$$
$$\cdots\cdots\cdots\cdots\cdots$$
$$M_{r-1}\,l_{r-1} + 2\,M_r\,(l_{r-1}+l_r) + M_{r+1}\,l_r = A$$
$$M_r\,l_r + 2\,M_{r+1}\,(l_r+l_{r+1}) + M_{r+2}\,l_{r+1} = B$$
$$\cdots\cdots\cdots\cdots\cdots$$
$$M_{s-2}\,l_{s-2} + 2\,M_{s-1}(l_{s-2}+l_{s-1}) + M_s\,l_{s-1} = 0$$
$$M_{s-1}\,l_{s-1} + 2\,M_s\,(l_{s-1}+l_s) = 0$$

The number of these equations is $s-1$, the same as the number of unknown moments. Their solution is best effected by the method of indeterminate multipliers. Let then the first equation be multiplied by a number c_2, the second by c_3, etc., the index of the as yet indeterminate numbers corresponding with that of the M in the middle term. Then let all the equations, thus multiplied, be added, and the resulting equation be arranged according to the coefficients of the unknown moments M_2, M_3, etc. Now, if we require that such relations exist between the multipliers, that all the terms in the first member shall reduce to zero, except the last containing M_s, the value of M_s is

$$M_s = \frac{A\,c_r + B\,c_{r+1}}{c_{s-1}\,l_{s-1} + 2\,c_s\,(l_{s-1}+l_s)}$$

And the values of the multipliers will be given by the equations

$$2\,c_2\,(l_1+l_2) + c_3\,l_2 = 0$$
$$c_2\,l_2 + 2\,c_3\,(l_2+l_3) + c_4\,l_3 = 0$$
$$c_3\,l_3 + 2\,c_4\,(l_3+l_4) + c_5\,l_4 = 0$$
$$\text{etc.,} \qquad \text{etc.} \qquad \ldots.$$

After deducing the values of c from these equations, the value M_s is at once known.

Again, if we multiply the equations of moments, beginning with the last, by the indeterminate numbers d_2, d_3, etc., all the moments except M_2 may be eliminated, and we have

$$M_2 = \frac{A\,d_{s-r+2} + B\,d_{s-r+1}}{d_{s-1}\,l_2 + 2\,d_s\,(l_1+l_2)}$$

and the multipliers will be given by the equations

$$2\,d_2\,(l_s+l_{s-1}) + d_3\,l_{s-1} = 0$$
$$d_3\,l_{s-1} + 2\,d_4\,(l_{s-1}+l_{s-2}) + d_4\,l_{s-2} = 0$$
$$\text{etc.,} \qquad \text{etc.,} \qquad \text{etc.}$$

The values of the numbers in the series c and d need only satisfy the equations as given above. Assuming then $c_2 = 1$, and $d_2 = 1$, we get the following:

(II)

$$c_1 = 0$$
$$c_2 = 1$$
$$c_3 = -2\,\frac{l_1+l_2}{l_2}$$
$$c_4 = -2\,c_3 - (2\,c_3 + c_2)\,\frac{l_2}{l_3}$$
$$c_5 = -2\,c_4 - (2\,c_4 + c_3)\,\frac{l_3}{l_4}$$
$$c_6 = +2\,c_5 - (2\,c_5 + c_4)\,\frac{l_4}{l_5}$$
$$\text{etc.,} \qquad \text{etc.}$$

$$d_1 = 0$$
$$d_2 = 1$$
$$d_3 = -2\,\frac{l_s + l_{s-1}}{l_{s-1}}$$
$$d_4 = -2\,d_3 - (2\,d_3 + d_2)\,\frac{l_{s-1}}{l_{s-2}}$$
$$d_5 = -2\,d_4 - (2\,d_4 + d_3)\,\frac{l_{s-2}}{l_{s-3}}$$
$$d_6 = -2\,d_5 - (2\,d_5 + d_4)\,\frac{l_{s-3}}{l_{s-4}}$$
$$\text{etc.,} \qquad \text{etc.}$$

which reduce to numerical form as soon as the lengths of the spans for any particular case are substituted.

Since the $s-1$ equations of moments are of the same form as the equations of the multipliers c and d, we must have

$$M_s = c_2 M_2, \quad M_1 = c_1 M_2, \text{ etc.},$$
$$M_{s-1} = d_2 M_s, \quad M_{s-2} = d_1 M_s, \text{ etc.},$$

or, if n indicate the index of any support,

$$M_n = c_n M_2 \quad \text{when } n < r+1$$
$$M_n = d_{s-n+2} M_s, \text{ when } n > r$$

Inserting in these the values of M_2 and M_s as found above, we have

$$M_n = c_n \frac{A\, d_{s-r+2} + B\, d_{s-r+1}}{d_{s-1}\, l_2 + 2\, d_s\, (l_1 + l_2)},$$
(III) when $n < r+1$

$$M_n = d_{s-n+2} \frac{A\, c_r + B\, c_{r+1}}{c_{s-1}\, l_{s-1} + 2\, c_s\, (l_{s-1} + l_s)},$$
when $n > r$

which give the values of the moments at all supports in terms of the quantities A and B, depending only upon the character of the load and its position in the span l_r, and the numbers c and d depending only upon the lengths and number of the spans of the girder.* To find their numerical value for any given case is hence a simple arithmetical exercise.

Example 1.—A continuous girder has four unequal spans, $l_1 = 80$ ft., $l_2 = 100$ ft., $l_3 = 50$ ft., and $l_4 = 40$ ft. (Let the reader draw the figure). On the span l_2 is a single load $P = 10$ tons, whose distance from the support 2 is $k\, l_2 = 40$ ft. To find the moments at the supports.

Since $k\, l_2 = 40$, and $l_2 = 100$, we have $k = 0.4$. Inserting then in (I), the values of k, l_2 and P, we find

$$A = 38400 \text{ tons ft.} \quad B = 33600 \text{ tons ft.}$$

Inserting next the lengths of the spans in (II), we have

$c_1 = 0$	$d_1 = 0$
$c_2 = 1$	$d_2 = 1$
$c_3 = -3.6$	$d_3 = -3.6$
$c_4 = 19.6$	$d_4 = 10.3$

Since the load is in the second span $r = 2$, also $s = 4$; hence $d_{s-r+2} = d_4 = 10.3$, $c_r = c_2 = 1$, etc., and $l_{s-1} = l_3 = 50$, etc. By inserting these values of c, d, l, A and B in (III), we obtain

$$M_n = \quad 82.01\, c_n, \quad \text{when } n < 3$$
$$M_n = -24.65\, d_{6-n}, \text{ when } n > 2$$

For the abutment or left hand support, we have $n = 1$, $c_1 = 0$, and hence $M_1 = 0$, for the second support, $n = 2$, $c_2 = 1$, and $M_2 = 82.01$ tons ft. For the third support, $n = 3$, $d_{6-n} = -3.6$, and $M_3 = 88.56$ tons ft. For the next, $n = 4$, $d_{6-n} = 1$, and $M_4 = -24.65$ tons ft. Lastly, for the right hand abutment, $n = 5$, and $M_5 = 0$. A positive moment, it will be remembered, causes tension in the upper chord of a truss, while a negative moment causes the reverse.

2. A girder of four equal spans has a load P at any point on the first span. Find the moment at each pier due to P.

Ans. $M_2 = \frac{11}{15} Pl\, (k - k^3)$, etc.

SHEARS AND REACTIONS AT THE SUPPORTS.

It is thus easy from (I), (II) and (III) to find the moments at all supports due either to single concentrated loads or to a uniform load over an entire span, and these are the only two kinds of loading which we need to consider in designing a continuous bridge. We next need the shear S_n at the right of any support due to these same loads.

In computing strains in a continuous truss we take up each span separately. The index n refers always to the particular span under consideration, while the index r referring to the span in which the load is for the moment considered, may be less than, equal to or greater than n. For single loads the shear S_r is given directly by (3), for a uniform load $P\,(1-k)$ in that expression becomes $\frac{1}{2}\, wl_r$, while for an unloaded span those terms disappear. Thus we have

$$S_r = \frac{M_r - M_{r+1}}{l_r} + P\,(1-k), \text{ for Fig. 6.}$$

(IV) $$S_r = \frac{M_r - M_{r+1}}{l_r} + \tfrac{1}{2}\, w\, l_r, \text{ for Fig. 3.}$$

$$S_n = \frac{M_n - M_{n+1}}{l_n}, \quad \text{when } n > r, \text{ or } n < r,$$

for the shear in the span l_n infinitely near to the support n.

The shear in the span l_n at a point infinitely near to the $n+1^{\text{th}}$ support is called S'_n (see Fig. 3). For its values we deduce

$$S'_r = \frac{M_{r+1} - M_r}{l_r} + P\, k, \text{ for Fig. 6.}$$

* In the *London Philosophical Magazine* for September, 1875, where the above demonstration was first given, the author has extended the method to girders with fastened or walled-in ends.

$$S'_r = \frac{M_{r+1} - M_r}{l_r} + \tfrac{1}{2} w l_r, \text{ for Fig. 3.}$$

$$S'_n = \frac{M_{n+1} - M_n}{l_n}, \text{ for } n > r, \text{ or } n < r.$$

The reaction R_n at any support n is evidently the sum of the shear S_n in the span l_n; and of the shear S'_{n-1} in the span l_{n-1} or for all cases

$$R_n = S_n + S'_{n-1}.$$

Example.—A girder of four equal spans has a single load P at the center of the third span from the left end. Find the reaction at the third support.

Ans. $R_3 = \frac{11}{16} P$.

SHEAR AND MOMENT AT ANY SECTION.

These are given directly by the simple conditions of static equilibrium. For a single load we have from (2), (see Figs. 5 and 6),

(V) $S = S_r - P$, for a section between P and $r+1$

$S = S_n$, for any other section.

as expressing the internal shear for any section x (see Figs. 5 and 6).

Also, we have

(VI) $M = M_r - S_r x + P(x - k l_r)$, between P and $r+1$

$M = M_n - S_n x$, for any other section,

for the internal moment for any section x in a span either unloaded or containing the weight P. Similar expressions may be also written as in Chapter I, if the load be taken as uniformly distributed.

Example.—A girder of three equal spans has a load P at the center of the first spans. What is the shear and moment at the center of the middle span?

Ans. $S = \frac{1}{2} P$, $M = \frac{3}{10} Pl$.

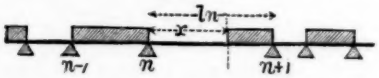
MAXIMUM SHEARS AND MOMENTS.

The formulae (I) to (VI) inclusive are sufficient in connection with an arithmetical process of tabulation to determine the maximum strains in all the pieces of a properly designed continuous truss. Having for instance to calculate tbe span l_n, we may take at every panel apex throughout the bridge a single load P, and compute the shear and moment at *any* section due to every possible position of P. These arranged in a table, afford a clear view of the distribution of loading giving the maxima; the greatest positive shear, for example, occurring when the live load covers those portions of the bridge which furnish plus values of S, while at the same time, it is absent from those portions giving minus values of S. Adding then all the plus values thus found, the maximum is determined by combination with that due to the always existing dead load.

It is therefore not absolutely necessary that the engineer should be acquainted with the theory of the distribution of loading giving rise to the maximum strains in the various pieces of the truss. As such a knowledge, however, is of great assistance in checking the accuracy of the calculation, we shall here state without demonstration the cases under which such maxima and minima arise.

First the shear; from this we obtain the strains in the webbing by the simple multiplication by a constant, a positive shear producing tension in a diagonal which slopes upward toward the left hand support. The maximum positive shear in the span l_n at the section whose distance from the support n is x, occurs under a distribution of loading such as is represented in Fig. 7, in which the shaded portions denote the live or rolling load. From this we see that the nearest span on the left and each alternate one

FIG. 7.

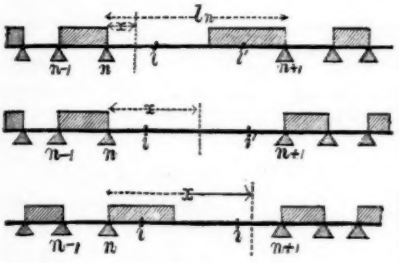


are covered with the live load; that from the section x to the support $n+1$ the live load extends; and that the second span on the right and each alternate one are also covered with the live load; all other portions being subjected only to the dead or actual load of the truss. The minimum positive, or, what is the same thing, the maximum negative shear obtains under exactly reverse conditions, the loaded portions in Fig. 7 being unloaded, while the empty ones receive the live load. Let the reader draw a figure for this case, and imagine the section x to move from n to $n+1$.

Next the moment; from this we obtain the chord strains by dividing by the constant depth of the truss, a positive moment producing tension in the upper

chord. Here the maximum positive moment in the span l_n, occurs near the support n under a distribution of loading like that represented in the first illustration of Fig. 8, near the middle of the span as in the second and near the support $n+1$ as in the last. Fig. 8 represents one and the same beam with the cases of loading causing maximum positive moments at three different sections in the span l_n, the first a section between n and a point i, the second between i and i' and the third between i' and $n+1$. These points i and i' are called *fixed inflection points*, and they enjoy the property that all loads on the spans to the

FIG. 8.



right of l_n, produce no moment at i; while all loads on the spans to the left of l_n produce no moment at i'. The position of these points depend only upon the lengths and number of the spans of the girder, or upon the numbers c and d given by (II). If the distance from n to i be denoted by i, and that from n to i' by i', the following simple formulæ

$$i = \frac{c_n l_n}{c_n - c_{n+1}}$$

$$i' = \frac{d_{s-n+2}\, l_n}{d_{s-n+2} - d_{s-n+1}}$$

will give the position of the fixed inflection points in any span l_n.

In order to render these distributions of load clear, let us imagine the section x to move from the support n to $n+1$. When the section is at n the live load covers the whole span l_n to render the moment at x a maximum, as x passes toward i the load recedes rapidly toward $n+1$, until when x reaches i the span l_n becomes empty, and the loads on the following spans shift as shown in Fig. 8. As x passes from i to i' the span l_n remains empty as in the second sketch and when it reaches i' the loads on the preceding spans shift. As soon as x passes i' the load begins to come on at n, which rapidly increases as x moves, until it covers the whole span when x coincides with $n+1$.

The arrangements of loading for causing the maximum negative moment in any section depend likewise upon the position of that section with reference to the fixed inflection points, and are in all cases exactly the reverse of those for the positive moment.

It will be seen, then, that the maximum moments between the supports and the fixed inflection points cannot be determined by cases of loading, for such cases are different for every section. In a girder of two equal spans for example, one of these points in each span coincides with the abutments, the others are at one-fifth the length of the span from the pier. Between those points the maximum strains are not to be found by parabolic curves of moments drawn from a few assumed arrangements of loading. Here have some late writers fallen into grave error.

The above completes, what seems to us a simple presentation of the theory of the continuous girder of constant cross-section. We have disconnected it entirely from the properties of the simple girder, have avoided the use of artificial angles and couples, parabolic moment and shear curves, static and elastic reactions and other paraphernalia which are too often introduced to complicate the subject. The formulae (I) to (VI) which may be written on a page of the engineer's note book include indeed the whole theory, and are sufficient for the determination of the maximum strains in a continuous truss of any number or lengths of spans.

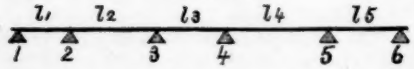
CHAPTER III.

We will now apply the above theory to the practical calculation of the strains in a continuous truss, and to show the perfect generality of our method we will take one of *five unequal spans*.

Fig. 9 shows the relative lengths of the several spans, each support and span receiving an index according to the notation previously adopted. The first span l_1 has a length of 70 feet, the

second l_2 of 100 feet, the third l_3 of 80 feet, the fourth l_4 of 120 feet and the last l_5 of 90 feet. This girder is to be subject to a live load of 0.8 tons

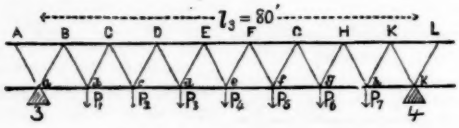
FIG. 9.



per linear foot per truss; the dead load we estimate at 0.6 tons per linear foot per truss. It is divided into panels of ten feet each and its height is also ten feet, the webbing being a simple series of isosceles triangles as shown in Fig. 10, which represents the span l_3 enlarged. The live load is applied at the panel points on the lower chord. It is required to calculate the maximum strains in all the pieces of the span l_3 due to the above live and dead loads.

We take up first the live load of 0.8 tons per linear foot, or eight tons per panel. Since every load in the span l_1 affects every section in l_3 in a similar manner, we may, instead of considering the separate panel loads on l_1, take them as uniformly distributed in the preliminary determination of the shear and moment at 3. (The load of eight tons at the points 1, 2, 3, etc., give reactions

FIG. 10.



only at those points, and cannot affect the span l_3). On the span l_1 there are seven panels and six apices, hence the live load in that span is $W_1 = 6 \times 8 = 48$ tons. In the same way we have on the spans l_2, l_4 and l_5, to consider the live loads applied at the panel apices as uniformly distributed over the spans; but in the span l_3 we must consider each panel load separately, since different arrangements of those loads give maxima for different sections. Thus we have

On l_1, the load $W_1 = 48$ tons,
On l_2, the load $W_2 = 72$ tons,
On l_3, the loads P_1, P_2, P_3, etc.,
(see Fig. 10) each equal to 8 tons,
On l_4, the load $W_4 = 88$ tons,
On l_5, the load $W_5 = 64$ tons.

We now turn to formulae (I) of the preceding chapter, and determine the quantities A and B due to each of these loads. For that on l_1 we have, for example, $W_1 = 48$, $l'_1 = 4900$, hence $A = B = 58800$. For P_1 we have $P = 8$, $l'_3 = 6400$, $k = \frac{1}{8}$, hence $A = 10500$, and $B = 6300$; in like manner, for P_2, P_3, etc., we place $k = \frac{2}{8}$, $k = \frac{3}{8}$, etc., and find for each a value of A and B. Thus we have for the several loads:

For W_1,	$A = B = 58800$	
For W_2,	$A = B = 180000$	
For P_1,	$A = 10500$	$B = 6300$
For P_2,	$A = 16800$	$B = 12000$
For P_3,	$A = 19500$	$B = 16500$
For P_4,	$A = 19200$	$B = 19200$
For P_5,	$A = 16500$	$B = 19500$
For P_6,	$A = 12000$	$B = 16800$
For P_7,	$A = 6300$	$B = 10500$
For W_4,	$A = B = 316800$	
For W_5,	$A = B = 129600$	

We next turn to formulae (II), and substitute the lengths $l_1 = 70$, $l_2 = 100$, etc., and thus obtain

$c_1 = 0$	$d_1 = 0$
$c_2 = 1$	$d_2 = 1$
$c_3 = -3.4$	$d_3 = -3.5$
$c_4 = 14.05$	$d_4 = 16.$
$c_5 = -44.567$	$d_5 = -54.8$

as the values of the multipliers c and d for the case under consideration.

We are now able to find from (III) the moments M_3 and M_4 at the supports 3 and 4 for each of the above loads. Since there are five spans, $s = 5$, $d_s = -54.8$, $d_{s-1} = 16$, etc.; substituting these in (III), we have

$$M_n = -c_n \frac{A\,d_{7-r} + B_{6-r}}{17032}, \text{ when } n < r+1$$

$$M_n = -d_{7-n} \frac{A\,c_r + B\,c_{r+1}}{17032}, \text{ when } n > r$$

n being *any* index (in our case either 3 or 4), and r the index of that span, which, for the moment, we regard as loaded. Taking the load on the first span, we have $r=1$, and since $n>r$, we use only the second of the above formulae, which becomes

$$M_n = -d_{7-n} \frac{A\,c_1 + B\,c_2}{17032} = -3.452\ d_{7-n}$$

Substituting in this $n=3$ and $n=4$, and we have

$$M_3 = -3.452\ (16) = -55.23 \text{ tons ft.}$$
$$M_4 = -3.452\ (-3.5) = 12.08 \text{ tons ft.}$$

Taking the load in the second span, we have $r=2$, and

$$M_n = -d_{7-n} \frac{A\,c_2 + B\,c_3}{17032} = -25.364\ d_{7-n}$$

in which, by making $n=3$ and $n=4$, we get the values of M_3 and M_4.

For the single loads on the span l_2, we must use the first of formulae (III) to obtain M_3, and the second to obtain M_4. Making then $r=3$, we have,

$$M_3 = -c_3 \frac{A\,d_4 + B\,d_3}{17032} = \frac{3.4}{17032}$$
$$(16\,A - 3.5\,B)$$

$$M_4 = -d_3 \frac{A\,c_3 + B\,c_4}{17032} = \frac{3.5}{17032}$$
$$(-3.4\,A + 14.05\,B)$$

and inserting in these the values of A and B, as given above, we find the moments at 3 and 4 from each of the loads from P_1 to P_7. For the load on the fourth span, we make $r=4$; for that on the fifth span, $r=5$; and the first of formulae (III) give the moments. Thus, by very simple arithmetical work, we obtain the moments M_3 and M_4 due to each of the single loads in l_2, and each of the uniform loads in the exterior spans, and arrange them in the second and third columns of the following table :

See Table on following column.

The last column of the table, which gives the shear S_3 in the span l_3 at a point infinitely near to the support 3, is found from the quantities M_3 and M_4 by means of formulae (IV). The load W_2,

Load.	M_3	M_4	S_3
	tons ft.	tons ft.	tons.
W_1	− 55.23	+ 12.08	− 0.841
W_2	+405.82	− 88.77	+ 6.182
P_1	+ 31.19	+ 10.83	+ 7.254
P_2	+ 45.36	+ 22.85	+ 6.281
P_3	+ 50.85	+ 33.93	+ 5.211
P_4	+ 48.00	+ 41.92	+ 4.078
P_5	+ 39.15	+ 44.65	+ 2.931
P_6	+ 26.64	+ 39.92	+ 1.834
P_7	+ 12.81	+ 25.85	+ 0.837
W_4	−158.10	+653.34	−10.143
W_5	+ 25.87	−106.91	+ 1.660

for example, gives a positive moment of 405.82 tons ft. at 3, and a negative one of 88.77 tons ft. at 4. From the last formula of (IV), we have then

$$S_3 = \frac{405.83 + 88.77}{80} = 6.182 \text{ tons.}$$

Also for the load P_3 on the span l_2, we have $P=8$, $k=\frac{3}{8}$, and from the first formulae of (IV)

$$S_3 = \frac{50.85 - 33.93}{80} + 8\,(1 - \tfrac{3}{8}) = 5.211 \text{ tons.}$$

and in the same way the other shears in the last column are computed. All of these refer, of course, only to the live load of eight tons per panel.

We are now ready to proceed with the computation of the maximum strains in the span l_3. And first we take up the webbing.

The maximum strain in any diagonal in Fig. 10, is equal to the maximum shear for that section multiplied by the secant of the angle between the diagonal and a vertical. We proceed first to find the maximum shears.

The shear at any section due to the dead load is constant, increases or decreases as the live load comes upon the bridge, and becomes a maximum or minimum under certain particular distributions of loading. To determine these it is only necessary to tabulate the shear due to each separate load. This is easily done from the values of S_3 and the formulae (V). In the following table the vertical column headed aBb includes the shears which may act upon the diagonals a B and B b, b C c those for b C and C c, etc. The horizontal column numbered 1 gives then the shears at every section due to the live loads ; the load W_1 for example producing a negative shear of

SHEARS. (See Fig. 10.)

		*a*B*b*.	*b*C*c*.	*c*D*d*.	*d*E*e*.	*e*F*f*.	*f*G*g*.	*g*H*h*.	*h*K*k*.
1	W_1	−0.84	−0.84	−0.84	−0.84	−0.84	−0.84	−0.84	−0.84
	W_2	+6.18	+6.18	+6.18	+6.18	+6.18	+6.18	+6.18	+6.18
	P_1	+7.25	−0.75	−0.75	−0.75	−0.75	−0.75	−0.75	−0.75
	P_2	+6.28	+6.28	−1.72	−1.72	−1.72	−1.72	−1.72	−1.72
	P_3	+5.21	+5.21	+5.21	−2.79	−2.79	−2.79	−2.79	−2.79
	P_4	+4.08	+4.08	+4.08	+4.08	−3.92	−3.92	−3.92	−3.92
	P_5	+2.93	+2.93	+2.93	+2.93	+2.93	−5.07	−5.07	−5.07
	P_6	+1.83	+1.83	+1.83	+1.83	+1.83	+1.83	−6.17	−6.17
	P_7	+0.84	+0.84	+0.84	+0.84	+0.84	+0.84	+0.84	−7.16
	W_4	−10.14	−10.14	−10.14	−10.14	−10.14	−10.14	−10.14	−10.14
	W_5	+1.66	+1.66	+1.66	+1 66	+1.66	+1.66	+1.66	+1.66
2	Live load +	+36.26	+29.01	+22.73	+17.52	+13.44	+10.51	+8.68	+7.84
	Live load −	−10.98	−11.73	−13.45	−16.24	−20.16	−25.23	−31.40	−38.56
3	Sums	+25.28	+17.28	+9.28	+1.28	−6.72	−14.72	−22.72	−30.72
4	Dead load	+18.96	+12 96	+6.96	+0.96	−5.04	−11.04	−17.04	−23.04
5	Max. +	+55.22	+41.97	+29.69	+18.48	+8.40			
	Max. −			−6.49	−15.28	−25.20	−36.27	−48.44	−61.60

0.84 tons in every panel or $S=S_3$, the load P_3 giving in the three panels on its left $S=S_3=+5.21$ tons and in the five on its right $S=S_3-P=+5.21-8=-2.79$ tons. A mere inspection of this table shows the distribution of live load causing the maximum or minimum shear in any section. Thus for the panel *d*E*e* the maximum occurs when those loads giving positive shears are present, namely, W_2, P_1, P_2, P_3, P_7, and W_5 and when all the others are absent, and the minimum occurs when only those giving negative shears are on the bridge. If then we add all the positive quantities in 1 and likewise all the negative ones and place the results in the horizontal column 2, we have for the panel *d*E*e*, +17.52 tons and −16.24 tons as the greatest and least shears which can occur in that panel due to the live load, and these need only to be combined with the shear due to the dead load to obtain the absolute maximum and minimum.

If the dead load be regarded like the live load as concentrated at the panel points on the lower chord, its effect will be a fractional part of that of the live considered as uniformly distributed. Adding algebraically the quantities in 2 we have in 3 the shears produced by a uniformly distributed live load of eight tons per panel, since this is the same as taking the algebraic sum of all the quantities in 1. The live load if extending over the whole bridge will then produce in *d*E*e* a shear of +1.28 tons, and since the actual dead load is three-fourths of the live, the dead load must produce in that panel a shear equal to $\frac{3}{4}\times 1.28 = 0.96$ tons. Taking then three-fourths of the quantities in the horizontal column 3 we have in 4 the shears due to the dead load of six tons per panel.

The shears in 4 always *must* exist, while those in 2 *may* exist under certain positions of the live load. The absolute maxima are therefore found by adding algebraically the quantities in those two horizontal rows. Thus for *d*E*e*, +0.96 always obtains, and if +17.52 also occurs their sum +18.48 is the positive maximum shear; and if −16.24 occurs, $+0.96-16.24=-15.28$ is the minimum or negative maximum. Placing these results in column 5 we have the required maximum shears in every section of the span under consideration. If the dead load shear in 4 is greater than the live load shear of opposite sign in 2 only one kind of shear can prevail; thus in *b*C*c* the greatest possible value is $+12.96+29.01=+41.97$ tons, the least possible is $+12.96-11.73=+1.23$ tons and the diagonals *b*C and C*c* will be subject to only one kind of strain. In the case before us three panels *c*D*d*, *d*E*e* and *e*F*f* have both a positive and negative

maximum and the diagonals in those panels may be subject to either tension or compression.

The maximum shears in 5 multiplied by *sec.* θ, or the secant of the inclination of diagonal to vertical give the maximum strains, tension of the diagonal slopes upward toward the left hand support, compression if it slopes downward. The depth of the truss being ten feet and the half panel length 5 feet, *sec.* θ is 1.118. We have then the following table of maximum strains in the

DIAGONALS. (See Fig. 10.)

B*a*	−61.7 tons
B*b*	+61.7
C*b*	−46.9
C*c*	+46.9
D*c*	−33.2 or +7.2 tons
D*d*	+33.2 or −7.2
E*d*	−20.6 or +17.1
E*e*	+20.6 or −17.1
F*e*	+28.2 or −0.4
F*f*	−28.2 or +9.4
G*f*	+40.5
G*g*	−40.5
H*g*	+54.0
H*h*	−54.0
K*h*	+68.3
K*k*	−68.3

in which + denotes tension and − compression.

In the same manner we may tabulate the moments at every section due to each load and deduce the maximum chord strains. For the upper chord panels A B, B C, C D, etc., the centers of moments are at the opposite vertices *a*, *b*, *c*, etc., and hence in formulae (VI) we must take 0, 10, 20, etc., as the successive values of x. To find the moment for C D due to the load W_1 on the span l_1, we have only to insert $x=20$, and the values of M_3 and S_3 as found above for that load (see Fig. 10), giving

$$M = -55.23 - (-0.841 \times 20) = -38.41 \text{ tons ft.}$$

the negative sign denoting that W_1 causes compression in the upper chord. Also to find the moment in the same panel due to the load P_2, we have as before $x=20$ and

$$M = 31.19 - 7.254 \times 20 + 8 \times 10 = -33.89 \text{ tons ft.}$$

In this way we readily compute the moments for every panel due to every live load and arrange them as in the following table of

MOMENTS FOR UPPER CHORD. (See Fig. 10.)

		AB.	BC.	CD.	DE.	EF.	FG.	GH.	HK.	KL.
1	W_1	−55.2	−46.8	−38.4	−30.0	−21.6	−13.2	−4 8	+3.6	+12.1
	W_2	+405.8	+344.0	+282.2	+220.4	+158.5	+96.7	+34.9	−26.9	−88.8
	P_1	+31.2	−41.4	−33.9	−26.4	−19.0	−11.5	−4 1	+3.4	+10.8
	P_2	+45.4	−17.5	−80.3	−63.1	−45.9	−28.7	−11.3	" 5.7	" 22.9
	P_3	+50.9	−1.3	−53.4	−105.4	−77.6	−49.7	−21.8	" 6.1	" 33.9
	P_4	+48.0	+7.2	−33.6	−74.3	−115.1	−75.8	−36.6	" 2.6	" 41.9
	P_5	+39.2	+9.8	−20.5	−49.8	−79.1	−108.4	−56.7	−6.6	" 44.7
	P_6	+26.6	+8.3	−10.6	−28.4	−46.7	−65.1	−83.4	−21.7	" 39.9
	P_7	+12.8	+4.4	−3.9	−12.3	−20.7	−29.0	−37.4	−45.8	" 25.9
	W_4	−158.1	−56.7	+44.8	+146.9	+247.6	+349.1	+450.5	+551.9	+653.3
	W_5	+25.9	+9.3	−7.3	−23.9	−40.5	−57.1	−73.7	−90.3	−106.9
2	Live load +	+685.8	+383.0	+327.0	+367.3	+406.1	+445.8	+485.4	+573.3	+885.4
	Live load −	−213.3	−163.7	−281.3	−413.6	−466.2	−438.5	−330.0	−190.7	−195.7
3	Sums	+472.5	+219.3	+45.7	−46.3	−60.1	+7.3	+155.4	+382.6	+689.7
4	Dead load	+354.3	+164.4	+34.2	−35.4	−45.0	+5.4	+116.4	+286.8	+517.2
5	Max. +	+1040.1	+547.4	+361.2	+331.9	+361.1	+450.2	+601.8	+860.1	+1402.6
	Max. −			−247.1	−449.0	−411.2	−433.1	−213.6		

The horizontal column 1 of this table shows at a glance the distribution of live load giving the maximum strain in any bay: in the bay B C for instance the

loads W_3 W_5 and P_4 to P_7 inclusive produce positive moments, and hence the greatest tensile strain obtains when those loads are on the bridge and all others are absent, while the least tensile strain in B C occurs when W_1, W_3, P_1, P_3 and P_5 are present and the others absent. Adding separately therefore these positive and negative moments, we have in 2, the greatest and least moments for every bay due to the live load. Adding those algebraically and we have in 3 the moments when the live load covers the entire bridge; taking three-fourths of the quantities in 3 we have in 4 the moments due to the actual dead load. Lastly combining the moments in 4 which always *must* exist with those in 2 which *may* exist, we get in 5 the absolute maxima and minima. For example, in C D we have due to the live load the moments +327.0 and −281.3, the sum of these or +45.7 is the moment when the live load extends over the whole girder, three-fourths of this or +34.2 is the value due to the actual dead load, and finally

$$+34.2+327.0=+361.2 \text{ tons ft.}$$
$$+34.2-281.3=-247.1 \text{ tons ft.}$$

are the maximum positive and negative moments, C D may then be subject to two kinds of strain.

Dividing these results by the depth of the truss and remembering that a positive moment causes tension in the upper chord, we have the maximum strains for the

UPPER CHORD. (See Fig. 10.)

A B	+104.0 tons
B C	+ 54.7
C D	+ 36.1 or − 24.7 tons
D E	+ 33.2 or − 44.9
E F	+ 36.1 or − 41.1
F G	+ 45.0 or − 43.3
G H	+ 60.2 or − 21.4
H K	+ 86.0
K L	+140.3

From this we see that the whole upper chord may under certain positions of the rolling load be subject to tension. This is due to the short length of the span compared with the adjacent ones.

The calculation of the maximum strains in the lower chord is entirely similar, the centers of moments being at the opposite vertices B, C, D, etc., and the corresponding values of x being 5, 15, 25, etc. We leave therefore as an exercise for the student the formation of the tabulation, merely giving the results to which it will lead, viz.

LOWER CHORD. (See Fig. 10.)

ab	− 76.9 tons
bc	− 41.4
cd	− 34.7 or + 34.6 tons
de	− 34.7 or + 47.8
ef	− 40.7 or + 47.1
fg	− 51.9 or + 34.0
gh	− 70.7
hk	−127.9

The strain sheet for the span l_3 (Fig. 9) is now finished, and in a similar way each of the other spans may be computed. The method we have presented is entirely general and applicable to any number of continuous spans, whether equal or unequal. In each case we take the load in the exterior spans as uniform and that in the span under consideration as applied at the panel apices, and find for each the quantities A and B from (I) and from the lengths of the spans we find by (II) the multipliers c and d. These enable us to deduce from (III) the moments at the supports due to each load, from which (IV) give us the shear. It is only in this preliminary computation of moments and shears that the calculation of continuous girders differs from that of ordinary simple trusses. In the latter the moments at the ends are known to be zero, and the shears coincide with the reactions which are found from the law of the lever. The simple truss is thus but a particular case of the continuous one as may be readily seen by placing $s=1$ in our formulae (I) to (IV). In an *end* span of a continuous truss the moment at the abutment is also zero and the shear is the same as the reaction.*

GIRDERS WITH SPANS ALL EQUAL.

This is one of the most common cases. Making in (II) all the l's equal, we have

$$c_1=d_1= 0$$
$$c_2=d_2= 1$$
$$c_3=d_3=-4$$
$$c_4=d_4= 15$$
$$c_5=d_5=-56$$
$$c_6=d_6= 209, \text{ etc.,}$$

* For an example of the computation of a continuous truss of two spans, see Van Nostrand's *Engineering Magazine* for July, 1875.

which are the well-known Clapeyronian numbers first deduced by the discoverer of the theorem of three moments.* Each of these numbers is equal to four times the preceding one less the one next preceding, and their signs are alternately positive and negative. They are here seen to be a particular case of our general formulae (II).

GIRDERS WITH SYMMETRICAL SPANS.

If the two end spans of the bridge are each equal to βl and the others each equal to l, the multipliers c and d become also equal. Their values are

$$c_1 = d_1 = 0$$
$$c_2 = d_2 = 1$$
$$c_3 = d_3 = -2 - 2\beta$$
$$c_4 = d_4 = 7 + 8\beta$$
$$c_5 = d_5 = -26 - 30\beta$$
$$c_6 = d_6 = 97 + 112\beta, \text{ etc.,}$$

each being equal to four times the preceding one less the one preceding that. Having established the value of β (usually taken at about 0.8) these reduce at once to numerical form. If β be unity the spans become all equal and the multipliers reduce to the Clapeyronian numbers.

Example.—A girder of four spans has a single load P in the second span at a distance kl from the second support; the two end spans being equal to $0.8\,l$ and the central ones to l. Find the moment at the second support.

Ans. $M_2 = P\,l(0.52k - 0.901\,k^2 + 0.381k^3)$

CONSTANT AND VARIABLE CROSS SECTION.

Having computed the maximum strains in a continuous truss, we choose for the various pieces cross sections of an area and form sufficient to resist those strains, thus making the girder one of uniform strength. The theory by which we have computed the strains supposes however that the cross section of the girder is constant. The question now arises what error is introduced by this hypothesis.

As we have been unable to present in the short limits of this paper the theory of the continuous girder with variable cross section, we cannot place before the reader a mathematical comparison of the two cases, and are hence obliged to rely on the computations of others and on general considerations.

Computations of strains in continuous girders have been made by Bresse, Mohr, Winkler, Weyrauch and others, considering the cross section both constant and variable. The general conclusion to be derived from their investigations is, that the maximum moments over the supports are greater, when the variable cross section is taken into account, but rarely more than six per cent. that the maximum moments near the centers of the spans are generally slightly less, and that the shearing forces do not sensibly differ.* For example, in a truss of two equal spans, the maximum moment at the pier is $0.125\ wl^2$ for constant cross section and $0.133\ wl^2$ for variable; the maximum negative moment is $0.070\ wl^2$ for constant and $0.067\ wl^2$ for variable, and the reactions of the pier are $1.250\ wl$ and $1.266\ wl$ respectively.

If then we compute continuous trusses as if they were of constant cross section, we are liable to slight errors in the chord strains. These strains are however computed on the assumption of a distribution of live load which can never occur in practice, and in proportioning the sections to those strains a factor of safety involving five or six-fold security is introduced. Considering then that it must be almost impossible for the live load to be arranged on the bridge as Fig. 8 represents, we may be well assured that our computations on the hypothesis of constant moment of inertia give greater strains than can ever obtain.

After having computed on both hypotheses a girder with four spans, two of sixty-five meters in length and two of fifty-two meters, Weyrauch says: "We are now able to answer the question, whether it is allowable to calculate continuous girders with variable cross section by the formulae for constant cross section, in the affirmative. The maximum moments arising from the two calculations differ but slightly. In our example, where the cross sections vary between 1 and $2\frac{1}{2}$, the greatest difference was 6 per cent. the next following only 2.7 per cent. The shears change scarcely

* See *Comptes Rendus*, 1857, p. 1076.

* Mohr, in *Zeitschrift des Arch. u. Ing. Ver. zu Hannover*, 1860, 1862. Winkler; *Die Lehre von der Elasticität*, p. 150. Weyrauch; *Theorie der continuirlichen Träger*, p. 22., p. 143.

at all. Only for bridges with extremely long spans, is it desirable to make a second computation on account of variable cross section."

LEVELS OF SUPPORTS.

In Chapter I we alluded to the fact that small changes in the relative levels of the piers produce great variations in the strains of the pieces of the truss. Continuous girders should not for this reason be used when the piers are liable to settle. Whether the supporting points are exactly upon level when the bridge is built is a matter of no importance, although, of course, no great differences can be allowed.

If in finding the equation of the elastic line we had considered the supports on different levels, a term containing those differences of level and the term E I would have entered the theorem of three moments. Now if a straight beam be laid across two points, a downward force is necessary in order that it should touch a third point at a lower level. If this downward force be furnished by the weight of the beam, a certain part of this weight will be effective in producing the deflection or satisfying the term E I, while the remaining part will act exactly as if the three supports were on the same level. But if the beam, instead of being originally straight, were of such a shape that it exactly fitted the three points it is in the same condition as the horizontal one after it has undergone the deflection. Hence its action is independent of the variations in level, for no exterior force is required to compel it to correspond with the points of support.

We therefore conclude, that if a bridge be built, by suitably adjusting its false works, corresponding to the profile of the piers, all the strains obtain exactly as if those piers were on one and the same level.

BEST LENGTHS OF SPANS.

Except the well-known rule that the lengths of the spans should be so adjusted that the cost of the piers and superstructure may be equal, there is little to be said upon this subject. Although most writers give a mathematical discussion of the most economical relations of spans, the fact that no two of them agree except in the simplest case, only indicates that the theory contains no principle which will lead to general conclusions.

Viewing the matter from a practical point of view, but not neglecting the investigations of mathematicians, we may give the following rules. For two spans the lengths should be equal. For others the span should be symmetrical, the interior ones being equal and the end ones shorter by about one-fifth or one-sixth, or making the central ones each equal to l, the end ones should be about $\frac{4}{5}\,l$ or $\frac{5}{6}\,l$. Such an arrangement equalizes the moments due to the dead load and being pleasing to the eye, it is advisable to regard it in designing continuous bridges.

PRACTICAL CONSTRUCTION.

In the construction of continuous bridges, the following points should be carefully observed:

1. The iron should be of a uniform qnality, and have undergone as near as possible the same process of manufacture.

2. The truss should be built with parallel chords, each capable of resisting either tension or compression; the webbing should be simple. With double and triple systems of webbing the strains cannot be accurately determined.

3. Joints in the chords should never be made over the piers.

4. The false works should be so adjusted that the bridge may be built with its points of support on the same relative level with the actual bed plates.

5. The bearing surface of the bridge upon the piers should be as small as possible consistent with considerations of strength and safety, and arrangements for longitudinal variation, due to changes in temperature, should be provided.

6. Continuous girders cannot be used if the piers are liable to variations in level after erection.

ADVANTAGES OF THE CONTINUOUS SYSTEM.

In favor of the continuous girder *versus* the simple one, we may mention:

1. Greater stiffness, since the deflection under a rolling load is much less than that of independent simple spans.

2. Ease of erection in cases where false works are difficult and expensive; the girder may then be built on shore and pushed out over the piers.

3. Saving in material for the piers,

since a less bearing surface is required than for two ends of single span bridges.

4. *Saving in iron, amounting to from twenty to forty per cent. over the ordinary construction of single spans.*

5. Simplicity of construction, when an angle of skew exists in the piers: in such cases the cross girders may be placed at right angles in the continuous structure, and the difficulties of oblique connections entirely avoided.

In a simple girder, whose length is l, and live load per unit of length w, the maximum deflection due to the live load is $\frac{5\,w\,l^4}{384\,E\,I}$. In two continuous spans each equal to l, the maximum deflection, which occurs when one span is covered with the live load, is $\frac{3.7\,w\,l^4}{384\,E\,I}$, or only three-fourths as much. With many continuous spans, the deflection is much less, its greatest value being in the end spans. In the case of a girder with horizontally fastened ends, the deflection is only one-fifth of that of ordinary simple spans.

The saving in iron is large, and alone sufficient to recommend the continuous system, particularly for long spans. This saving occurs wholly in the chords where material can best be spared. In the webbing the quantity of material is slightly increased. The exact percentage of saving depends upon the number and lengths of spans, the proportion of live to dead load, the arrangement of webbing, and will be the same in no two cases. In the example of Fig. 9, the center span which we computed does not afford scarcely any saving in material owing to the influence of the larger adjacent spans. For girders of two hundred feet in length with spans nearly equal, calculation indicates a saving of about thirty per cent. For the extreme case—a single span with horizontal fixed ends—the saving is fifty per cent.

DISADVANTAGES OF THE CONTINUOUS SYSTEM.

In our last chapter we referred to an article by Charles Bender, C. E., which contains many ingenious arguments against the use of continuous bridges. There are, in fact, fifteen "conclusions" to which he is led and which may be seen by the reader on p. 109 of the current volume of *The Journal of the American Society of Civil Engineers.* Of these we will give a short abstract and append a running commentary.

1. The theoretical calculation of curves of moments, without consideration of proportions and details, is exceedingly fallacious.—Other things being equal, the calculation of strains does furnish an estimate of amounts of material. The method of curves moreover is neither so accurate nor so quick as our process of tabulation.

2. This fallacy will be greater, if the theory stands upon false premises.—Undoubtedly.

3. The theory of continuity is fallacious and unreliable, because it supposes the coefficient of elasticity constant, whereas it has been shown that it may vary for wrought iron from 17,000,000 to 40,000,000 lbs. per square inch.—In our last chapter we have shown that the proper interpretation of the variability of E is, that different qualities of iron have different degrees of elasticity. The values of E, from which it is concluded that the laws of flexure are fallacious, were in fact found by the theory itself from the measured deflections of beams, and it is hence more than fallacious to regard them as condemning that theory.

4. With several diagonal systems the strains in a continuous girder cannot be calculated, but only guessed.—A good objection and it applies also to simple girders and draw spans.

5. The theory needs a correction if the chords are made variable in cross section.—The amount of this correction we have indicated above.

6. The calculation of continuous trusses is excedingly tedious, and if generally introduced would greatly impede the business of bridge building in this country.—A conclusion to which those who know how to calculate decidedly object. For a construction costing half a million dollars, it matters little whether one day or one week be spent in computation, and if the one week saves ten per cent or more on the cost, it is certainly well employed.*

* In the discussion of this subject at the late Engineers' Convention, one of the speakers mentioned an instance where the strain sheet for a continuous revolving draw bridge was furnished for $40. As that strain sheet was made by the author of this paper it is not improper that he should remark that its price would have been considerably less had the computations been made by tabulation of apex loads, instead of by the consideration of cases of loading.

7. Pieces which resist two kinds of strain must be proportioned to resist the maximum tension plus the maximum compression.—Further experiments are much needed in this connection; if Woehler's conclusions are confirmed, pieces must be so proportioned and hence the percentage of saving lowered.

8. Continuous girders require very accurate workmanship.—Are we to infer that ordinary trusses do not?

9. The foundations and masonry of the piers must be of excellent quality.—Does not the same hold for the simple girder? See No. 11.

10. If the girders are built on shore and pushed out over the piers, additional computations must be made and extra pieces introduced.—The additional computations are of the simplest character and in many cases no extra pieces would be needed.

11. If improperly placed on their bed plates, greater strains arise than are contemplated, an inch difference in level producing great variations in strains.—We have shown above that unless piers are liable to settle after the erection of the bridge, such differences in level produce no effect.

12. If one chord be protected from the heat of the sun the strains are much disturbed.—The camber of the bridge is altered, as also occurs in single spans. It should be remembered however that although certain strains cause a curvature, a certain curvature does not necessarily cause corresponding strains.

13. Continuous bridges have proved to be more economical in Europe than simple spans, because the latter have been improperly proportioned.—Trial is necessary to prove that they would or would not be more economical in this country.

14. By designing two bridges of 200 feet each, a two span continuous truss twenty-five feet high, and a simple truss 27 feet high, with different details, Mr. Bender finds that the latter is more economical.—Perhaps for other proportions this might be reversed. In a comparison of amount of material, ought not other things to be taken equal?

15. Continuous bridges deflect as much as single spans.—Not if they have the same height and span, and are subject to the same loads; a fact which every schoolboy knows.

In regard to objections 2, 6, 7, 8, 9, 10, 12 and 13 one remark further is necessary. They are objections which may be made to every new proposed construction in engineering art. In the days of wooden bridges, they were advanced against the use of iron; they have been made against the suspension system and against the braced arch. But their value can be estimated in only one way, *by trial.* On the other hand theory can estimate one at least of the advantages claimed for the continuous systems, and that estimate is a saving of twenty to forty per cent. in material; how much of this must be deducted for extra care in workmanship, labor of erection, effects of temperature, or variations in the elasticity of the material can only be determined by the actual erection of continuous bridges, by experiments extending through a long series of years.

Having thus stated briefly, but fairly, the arguments for and against the use of continuous bridges, we leave it to practical builders to decide whether or not the system is worth a trial. Other nations have long been using it; profiting by their experience and by our own improved methods of manufacture and modes of erection, it may, perhaps, turn out that we shall find it better and more economical than the present system of single independent spans.

HISTORY AND LITERATURE.

The literature on the theory of continuous girders is very extensive in the German and French languages, and very limited in English. We can only give here a few hints concerning its development and history.

About the year 1825, Navier founded the present theory of flexure by introducing the hypothesis that the extensions and compressions of the fibers on each side of the neutral axis were proportional to their distances from that axis. From this he deduced the equation of the elastic line, and applied it to the discussion of continuous girders. His method consisted in determining first the reactions of the supports, and from these the internal forces or strains, which, although the most logical, was

exceedingly tedious in practice. In the following works the reader may find detailed information concerning his method:

Kayser: *Handbuch der Statik*, Carlsruhe, 1836, chap. X.

Molinos et Pronnier: *Traité de la construction des ponts metaliques*, Paris, 1857.

From the time of Navier to the publication in 1857 by Clapeyron of the method of using the moments over the piers as auxiliaries in the computation instead of the reactions, many continuous girders were built in France, Germany and England. Among these may be mentioned the Britannia tubular bridge, of four spans, two of 231 feet, and two of 460 feet; the Boyne Viaduct with three spans of 141, 267 and 141 feet; and the bridge over the Weichsel at Dirschau with *six* continuous spans, each 397 feet in length. By Clapeyron's happy discovery of the theorem of three moments, a great impetus seemed to be given toward the erection of such bridges, for in the twenty years following 1857, we find them extensively built in Germany and France, although in England the unfortunate example of the Britannia tube caused a tendency to other forms of construction. A mere list of such bridges would occupy pages. They are generally of shorter span than those mentioned above, rarely exceeding 300 feet, while the number of spans varies from two to seven.

To give here a list of the books which has appeared since Clapeyron's time will also be impossible. We can only indicate two or three which are at the same time valuable and easily accessible:

Bresse: *La mécanique appliquée*, Paris, 1865. (Vol. III contains a tolerably complete mathematical discussion, with tables for facilitating the calculation of moments.)

Winkler: *Theorie der Bruecken*, Vienna, 1872. (Contains the graphical method of Culmann and Mohr, with also analytical investigations.)

Weyrauch: *Theorie der continuirlichen Traeger*, Leipzig, 1873. (A complete analytical discussion of the whole subject. The best work which has yet appeared.)

In our own country have been issued during the past year the works of Greene, Herschel and DuBois, each of which contains valuable contributions to the literature of the subject, and which should be in the library of every student of engineering. On the other hand, works by English authors, which treat of the subject at all, do it in such an imperfect and unsatisfactory manner, that we are forced to consider them as twenty years behind the age.

As the above mentioned works treat only of the theory and calculation of continuous girders, we ought perhaps to say that a book giving an account of the most important continuous and simple, together with suspension and arch bridges, is the admirable descriptive work by Heinzerling, *Die Bruecken in Eisen:* Leipzig, 1870, which is illustrated by over a thousand engravings, and presents a complete history of iron bridge construction.

THE WATER SUPPLY OF PARIS.

From "The Builder."

THREE years ago there was published a valuable Report, bearing the authoritative name of M. Maxime du Camp, respecting the water-service of Paris. Since that time, a curious development has taken place, proving to the great French capital that it cannot depend upon the river for its constant and natural supply. With that regard, therefore, which the French invariably exhibit for public interests of a social kind, a commission was issued, and its statement is in print, if not yet in circulation. But its publicity may be expected within the next few days. Meanwhile a brief recapitulation of the contents may be useful. Paris, it may justly be said, has taken the lead among the cities of Europe, in the matters of water and light, dark and miserable though its traditions have been. And yet it is a city, in this respect, of want and sacrifice; for there

was, until lately, no worse-watered town to be discovered through the length and breadth of Europe. In plain truth, its principal streets have been considered to the disregard of its lesser thoroughfares, and the whole have suffered from the effects of this absurd municipal favoritism. But the new system is in full operation at present, and Paris enjoys now a real abundance of water. There is no quarter in which the mere turning on of a tap will not ensure an instant and copious service. Reservoirs, aqueducts, and fountains are far more numerous than in London. Paris, in fact, has escaped from what the Arab picturesquely calls "the hour of thirst." Yet this is an improvement of altogether recent date. When the last Report was published, during the earlier years of the Second Empire, the Cité, alone, of all that beautiful metropolis, enjoyed its pure and abounding issue from the hills around; and this water was irreproachably sweet. It was not derived from the Seine, which then held in solution a Thames-load of abominations and nuisances: yet this condition could not endure. The uncorrupted current flowed over a low marsh, and was polluted by it. But there was an explanation of this result, and it accounted for a great fact in the history of Parsian mortality during the ensuing years. The new aqueduct passed by a tunnel, through "the Mountain of Martyrs," among graves and the uncoffined dead, and also through the vaults of a churchyard for the incurables, the consequence of which was the poisoning of an entire district for from between twenty and thirty years. However all this has been abolished, now the laughing little stream, the Bièvre, runs in place of the sour old sewer, and sparkles into the Seine, just under the gray, unfinished towers of Notre Dame; and the visitor is astonished to be told that those are the waters of Arcueil, brought by an aqueduct, *temp.* 1544, Roman and Julian in age and character,—*Guarda è passa.* There is not a syllable of truth in the legend, from beginning to end. These things are made up of Roman brickwork, and have no more true antiquity about them than the bridge of Austerlitz. Nevertheless, they possess, no doubt, a particular interest. The monks of Saint Lawrence were determined to get drinking-water without having recourse to the Seine. They excavated, in an Indian manner, vast tanks at Romainville, Bruyères, Menilmontant, and Saint Gervais, and afterwards at Saint Martin-des-Champs,—Saint Martin's-in-the-Fields, of London popularity,—and they did more than this, they dug a subterranean aqueduct, 7,000 ft. in length, which existed before the New River was actually in contemplation. Were these the works of ordinary workmen? No; of monks, who thus employed their spare, though not indolent time. Let us honor them for it. Yet it must be admitted that they were, in a degree, selfish. They began, at any rate, by appropriating the waters of the wells and other sources to their own gratification. But King Philippe-Augustus put in a claim on behalf of Paris; and after recognizing his merits, we must, indeed, skip at least a hundred pages of the Report, in order that our own time may be reached.

Suppose, then, fifty ordinances, until we reach the present day. Paris now drinks from the Seine, from L'Ourcq, and from the Marne, from the wells of Arcueil and of Huis, and from the artesian wells of Grenelle and Passy. Its fountains are also fed from the steam apparatus at Chaillot, and from the ingenious mechanism at Belleville; and in all these places it is remarkable that the local territorial incidents are similar; that is to say, that the rain falling on hills does not descend altogether into the valley, but is, in a main part, absorbed by the slopes, and furnishes Paris with its largest supply of water. Of course, however, advantage is taken of every opportunity possible for gathering into distinct channels, tunneled or not, all the sweet water that can be accumulated, in order, both to spare the Seine,—which is exceedingly impoverished in its current, at times,—and to provide a purer draught for the citizens. Still, the hollows cut through the earth, and constructed of unmortared masonry, from Belleville and the Prés-Saint Gervais, are neither more nor less than common drains, though used for drinking purposes, and they bring all manner of abominations with them. They are sewers, in point of fact, as M. Maxime du Camp confesses, and it is to be wondered at why Paris takes the trouble to be

proud about them. So much is admitted in the official Reports—and French official Reports, we are bound to say, are, as a rule, unsparing. But there is a brilliant side of the picture, to which we willingly turn. It is that of a vast system, perfectly regulated, of reservoirs carefully covered in, not architecturally handsome, but protected from all unhealthy influences, with immense currents, perpetually pouring through them,—tomb-like, the Parisians say,—and piled over with "brutal" masses of architecture to keep the water cool. Among the new structures may be seen many of older date; as early, indeed, as the middle of the seventeenth century, the outer walls and embankments of which are hoary with lichens, although the tanks are as pure and as free from noisesomeness as though they were the works of the Moguls, and had belonged to the marble groups of Agra. These were architectural efforts, however, and no more recent monuments of a similar Parisian ambition remain. Notwithstanding, the water-system of Paris is improved, from year to year, and it is scarcely too much to say that every drop from the fountains of the earth, in the neighborhood of the capital, or wherever it can be reasonably sought for, is utilized. Generally speaking, thirsty Paris has its thirst quenched from the north. The waters of the south are soft, and slightly unwholesome, though they sparkle brilliantly enough in the way of fish ponds and fountains. The supply from them, however, amounts to not more than a million of gallons a day, which is a fractional total for so large a city; and it is principally gathered through an aqueduct across the valley of the Bièvre, a work Roman in magnitude, with 500 yards of archway 70 ft. above the common road, in many parts, and with magnificent spans across canals and roads. Indeed, some relics of the Julian period are still to be traced in this monumental work, which French archæologists, however, effect to despise, for the plain, though insensate, reason that it has been put to common uses. It stops short, however, about 8,000 yards from the point of general distribution. Here is a gigantic hall, resonant with "the voices of many waters;" immense pipe-holes pierce its walls; a canal runs through the centre of the floor; there are pathways on both sides of it; galleries run above, with white arched windows, letting in as much light as can be expected; the whole perspective suggests a prodigious cloister, with an ominous, offensive sound, though not much of a repulsive scent pervading it. Taken for all-in-all, indeed, the atmosphere is rather refreshing and pleasant than otherwise. But it is impossible not to detect,—as the Report, indeed, avows,—the influence of the weather, above and beyond all artificial arrangements or precautions. Thus, when heavy rains have fallen, wells are full, rivers have overflowed, and even the gutters have been choked, the water-supply of Paris is out of order,—is unhealthy, is contaminated, and bursts with black bubbles into the cisterns, which, as every one knows, are always exposed to the rainfall. These are points especially insisted upon by the authors of the Report, who declare that numbers of water-sources, once famous in France, and especially in Paris, have been stopped up for architectural and other purposes, and who also remind their fellow-citizens that they were in danger—the Seine notwithstanding—of something like a water-famine during the German siege. Six steam-pumps were kept at work, by day and by night, in that sad time, at the port d'Anglais, the Maison Alfort, the Quai d'Austerlitz, Auteuil, Saint-Ouen, and Chaillot, and even then the supply threatened to become a devastating scarcity. The cost of the machinery, and of its operation, was among the most remarkable items in the Budget of Paris, during that calamitous year. The Ourcq, however, flowed freely through its tunnels, which, upon their approach to the capital, are constructed of massive blocks, solid as those of a pyramid. There are sections, indeed, through which they pierce a kind of comparatively valueless coal-field, but through the lateral avenues of which water rushes at a tremendous rate, and in an enormous volume, though, at La Corderie, the Report tells us, a wheel of 90 ft. circumference is required. It is strange enough to find that, in this vast water gallery, a triple grating is needed to prevent the ordure of the suburbs from floating *into*, rather than *out from*

the subterranean aqueducts of Paris. And, most repulsive of all, perhaps is the growth, upon stone walls, of the "vegetable spider," bred at 26 degrees, *a zéro*, and a creature sufficient to infect any water under heaven. But the animalization of the lakes, streams, and ponds of Paris is not, just now, all important. The capital of Paris is seated upon a curve of her capital river, which, by Frenchmen, in their odd way of talking, is called a gigantic corkscrew. Whatever that may mean, it has nothing to do with the scheme at present in view,—which is, through a grand series of hydraulic works, to secure for Paris a plentiful supply of water to drink,—water well selected and scientifically certified, selected from known sources, and free, so far as can be ascertained, from malarious influences. Eleven years have been devoted to this task, and the results have been very creditable to the public spirit of the Government of France. Thus, the Commissioners have pointed out the sources of the Lhuis, at Parjois itself; they have explored all the tributaries of the Vanne; they have gone to the fountains of the Yonne, and, when we know that this means the difference positively between food and poison, we shall comprehend the importance of the general topic. Eleven pestilential rivulets flow their filthy weight into the Yonne, which creeps black and heavy, into Paris, like a crime, and no tree, no flower, no herb of any kind will flourish upon its banks, where children are supposed to be nurtured up to girlhood and womanhood, nevertheless. Five years ago, an attempt at reform was commenced; there were new aqueducts opened; new, pure, clear conduits, cool and close-roofed, to supply the people of Paris, free from metallic taint, and from all chemical associations. Then was underaken, and soon was completed, the existing system of Parisian waterworks. In their own superb language, the French commissioners report, that "they constitute one of the most inspiring works which it is in the power of man to contemplate." We pass on, without feeling so precisely sure upon the point; but the new Parisian works are unquestionably imposing, and, at the same time, not obtrusive. The original design was, happily enough, abandoned. There are no bronze tritons, and there are no marble nymphs. There is a reservoir, three acres in length and width, with a uniform depth of 15 ft., perpetually full, banked up, on all sides, by a forest of palisading to support the earthworks, and, although this is by no means the principal source of the Parisian supply, it is a main one, and exceedingly important. There are sixteen others, indeed, but, in comparison, they are insignificant.

The official Report, just published, mentions only nine of them, the others being subsidiary, and, in a way, auxiliary to the rest.

ON THE LANCASHIRE BOILER, ITS CONSTRUCTION, EQUIPMENT, AND SETTING.

By Mr. LAVINGTON E. FLETCHER.

Transactions of the Institution of Mechanical Engineers.

The Lancashire type of boiler differs only from the Cornish in one point, namely that the Lancashire boiler has two furnace tubes whereas the Cornish has but one. In both types of boiler the shell is cylindrical, the ends are flat, and the furnace-tubes are carried through from front to back below the ordinary water line, while the boilers are laid horizontally and fired internally. Internal firing is essential either to a Lancashire or to a Cornish boiler. It is a mistake to speak of an externally-fired Lancashire or an externally-fired Cornish boiler, though this is frequently done. If the fires are taken out of the furnace-tubes of a Lancashire boiler and put underneath, it is a Lancashire boiler no longer, but becomes an externally-fired double-flued boiler; and if a Cornish

boiler be treated in the same way, it becomes an externally-fired single-flued boiler. These boilers owe their names to the counties in which they were first brought into general use The single-furnace boiler was introduced early in the present century by Trevithick, in Cornwall, and is therefore called Cornish. The double-furnace boiler was introduced in 1844 by Fairbairn and Hetherington, in Manchester, and is therefore called Lancashire.

In laying down Lancashire boilers, the fact has been too frequently lost sight of that directly a fire is lighted within them they begin to move, the flat ends to breathe outwards, the furnace tubes as well as the shell to hog upwards, and the whole structure to elongate. If sufficient allowance is not made for these movements, straining and sometimes rupture occurs, while the tendency to this is frequently aggravated by putting in an extra thickness of metal with a view of adding strength, the additional thickness increasing the unequal expansion of the parts. For some years the writer has had opportunities of observing a large number of boilers of the Lancashire as well as other types, in work under the inspection of the Manchester Steam Users' Association; and from these observations he has endeavored to mature as complete a boiler in construction, equipment, and setting, as possible. In doing this the following points have been kept in view :—to make the boiler safe for a working pressure of from 75 to 100 lb. per sq. in.; to make the structure elastic, so that it may not be rent by the movement of the parts consequent on alternate expansion and contraction, but may be able to endure the work of years; and to set the boiler and arrange the fittings so that the whole shall be above board and accessible to inspection. The writer does not agree with the view too generally held, but most obstructive to improvement, namely, that anything will do for a boiler, and that it is only a boiler after all. He thinks that a boiler should receive as much attention as an engine; that it should be made with as much accuracy and attended with as much care; that the fireman should not be condemned to work in a dark, dirty hole, called a stoke-hole, and the boiler assumed to be necessarily black and grimy; but that the boiler should be placed in a suitable house kept bright and cheery, and the fittings as well as the whole structure kept clean and in first-rate working order; also that the fireman should be stimulated to become as proficient in the art of using his shovel and managing the fire as a fitter in using his file and erectlng an engine. If this practice, happily adopted by some, were to become general, and first-class boilers were laid down instead of low-priced ones, the scientific boiler-maker would have fairer scope, the steam user would derive economy, and the public would be benefitted by the prevention of explosions as well as by the abatement of the smoke nuisance.

The Lancashire boiler has many variations, besides the simple form already described. There is the Galloway boiler, in which the furnaces instead of running through from one end to the other unite in an oval flue strengthened with conical water pipes. There is the Multitubular, in which the furnace-tubes unite in a combustion chamber, from which a number of small flue tubes about three inches diameter and six feet long run to the back of the boiler. There is Hill's Multiflued boiler, in which seven flues about eleven inches diameter and eight to ten feet long take the place of the small flue tubes in the multitubular boiler. There are also others in which the furnace tubes branch off to the sides or the bottom of the shell, instead of running right through to the back end. To all these variations of the Lancashire boiler, and also to the Cornish, this paper applies as regards the construction of the shell and furnace-tubes, as well as in regard to the equipment and setting of the whole.

To assist in the construction of Lancashire boilers for high pressures, the Manchester Steam Users' Association authorized the making of a boiler expressly for undergoing a series of hydraulic bursting tests; and the manufacture of the boiler was entrusted to Mr. Beeley, of Hyde Junction, who has heartily seconded the views of the Association and rendered valuable assistance in the prosecution of the trials. This experimental boiler is seven feet diameter, which is the usual size for mill service.

It is adapted for a working pressure of seventy-five pounds per square inch, and its construction is as subsequently described. A number of experimental bursting tests have already been made, careful observations being taken of the behavior of the boiler while under pressure. These tests have already furnished valuable information, and when completed will be fully reported. Some of the results are given in this paper. In order to preserve the precise form and character of the rents produced, the solid plating around them has been cut out of the boiler intact; four of these specimens are exhibited at the meeting. An actual end plate of a boiler 7 feet diameter, equipped with the usual fittings, is also exhibited. This boiler front has been made by Mr. Clayton, of Preston, who was one of the earliest to assist the writer in getting up a first-class boiler equipment for the Manchester Steam Users' Association.

CONSTRUCTION.

Dimensions.—Short boilers are found to do more work in proportion than long ones; this has been confirmed by experiments on the rapidity of evaporation by Mr. Charles Wye Williams and others. Also short boilers strain less than long ones, and are therefore less liable to need repair. A length of thirty feet should be the maximum, while with regard to the minimum some Lancashire boilers to suit particular positions have been made as short as twenty-one feet and found to work well, though the fittings become rather crowded. The length recommended and now generally adopted is twenty-seven feet.

The diameter of the boiler is governed by the size of the furnaces, which should not be less than two feet nine inches to admit of a suitable thickness of fire and afford convenience in stoking. Thick fires are more economical than thin ones. The space betweeen the two furnace-tubes should not be less than five inches, and that between the furnace tubes and the side of the shell four inches, in order to afford convenient space for cleaning and for the free circulation of the water, as well as to give sufficient width of end plate for enabling it to yield to the expansion and contraction of the furnace-tubes. With this width of water space it will be found that furnace-tubes having a diameter of two feet nine inches require a shell of seven feet, which will afford a headway of about two feet nine inches from the crown of the furnaces to the crown of the shell. A furnace three feet diameter gives room for a better fire than one two feet nine inches, but it requires a shell seven feet six inches diameter. For high pressures, the smaller diameter of seven feet is generally preferred, and has come to be adopted as a standard size for mill boilers throughout Lancashire, though one of seven feet six inches makes a good boiler. The diameters both of the shell and of the furnace-tubes are measured internally, that of the shell being taken at the inner ring of plating.

Ends.—The ends, more especially the front, are the seat of the grooving action which occurs in Lancashire boilers when disproportioned. These grooves occur inside the boiler and around the furnace mouth. They are the product of mechanical and chemical action combined. The plate is fretted by being worked backwards and forwards by the movement of the furnace-tubes consequent on the action of the fire, and when in that condition is attacked by the acidity of the water. To prevent this grooving, the ends should be rendered elastic so as to endure the buckling action without fatigue. To secure this elasticity there should be not only a sufficient width of end plate between the two furnace-tubes as well as between them and the shell, as already explained, but also a space of nine inches between the center of the bottom rivet in the gussets and those at the furnace mouth. Also five gusset stays are found to work in better than any other number. With five gussets, one falls on the center line, which is not only the weakest part of the front end plate and thus where it requires the most support, but also where it can be held fast without resisting the movements of the furnace-tubes. The part of the end-plate that should be left free is that immediately over the furnace crowns. With four gussets, the end plate is more unguarded at the center, which is the weakest part, and more bound immediately over the furnace-tubes, which is the line of motion.

The thickness of the end plates is

sometimes as much as three-quarter inch for pressures of sixty pounds per square inch. This thickness however is quite unnecessary, and only tends by its rigidity to cramp the furnace-tubes and strain the parts. Half an inch has been repeatedly and successfully adopted in boilers for pressures of seventy-five pounds per square inch, and nine-sixteenths inch when that pressure has been exceeded. These thicknesses have proved amply sufficient.

In applying the hydraulic test to boilers of the construction and proportions now described, before leaving the maker's yard, it is the practice to carry the pressure up to about 150 lb. per sq. in., and to strain fine cords across the flat ends to act as straight edges from which to gauge the ends at twelve points, measurements being taken before the test, during the test, and after the test. It is found as a rule that the plate under pressure bulges outwards at the center from one-sixteenth to one-eighth inch, and on the removal of the pressure returns to its original position without suffering any permanent set. In the experimental hydraulic bursting tests, the ends, though only one-half inch thick, have stood a pressure of 275 lb. per sq. inch without leakage or any appearance of distress; but on the pressure being raised to 300 lb. the front end plate displayed signs of weakness in the vicinity of the mudhole beneath the furnace-tubes. With this exception, the greatest bulging was one-eighth inch at the front, and three sixteenth inch at the back, while the greatest permanent set was only one-sixteenth inch.

Longitudinal stays are frequently introduced to assist the end plates. In the experimental test the longitudinal stays were taken out, so that it is clear they are not absolutely necessary where the gussets are substantial. Should it however be thought desirable to adopt them, either as an assistance to the gussets when too weak, or as an extra precaution, they will be found easy of introduction. It will be observed that they are secured at each end with double nuts, one inside the boiler and one outside, and are placed as much as fourteen inches above the level of the furnace crowns, and as close together as convenience will allow. When placed directly over the furnace-crowns, and only a few inches above them, they confine the furnace-tubes too strictly, and straining ensues. A single stay on the vertical center line of the front end plate is correct in principle, but two are more convenient in application.

To increase the elasticity of the front end plate, it is attached to the shell by an external angle-iron rather than by an internal one or by flanging. It is not necessary to attach the end plate at the back of the boiler with an external angle-iron, aud when this has been done the angle-iron has been found to be injured by the action of the flame. Both of the end plates, instead of being made in two pieces riveted together at the joint, are welded, so as to afford a flat surface, which is more convenient for the attachment of the mountings. Also both of them are turned in the lathe at the outer edge, so as to be rendered perfectly circular, and are bored out at the openings for the furnace-tubes.

Furnace-Tubes. — The longitudinal joints in the furnace-tubes are welded when the plates are of iron, and double riveted when of steel, each belt of plating being made in one length and thus having but one longitudinal joint. All the transverse seams of rivets are strengthened with Adamson's flanged joint, or with an encircling hoop either of Bowling iron, T iron, or other approved section. One of the evils that has attended internally-fired boilers has been the frequent collapse of the furnace-tubes; but this danger is completely avoided by strengthening the tubes as just described, whereby, instead of being weaker than the shell as before, they are rendered stronger. This has been shown by the experimental bursting tests, in which, while the shell has been burst repeatedly, the furnace-tubes have not suffered at all, nor shown any movement on being gauged. In some cases Petrie's pockets, and in others Galloway's conical water pipes, are introduced as a precaution against collapse; while in others again the water pipes are made parallel, and either riveted or welded in place, so as to form one piece with the flue tube. In all cases however the transverse seams of rivets over the fire should be strengthened with flanged seams or encircling hoops; and it is

considered desirable to continue this mode of construction throughout the entire length of the boiler, whether water pockets or water pipes are introduced or not. The thickness of the plates in the furnace-tubes is sometimes as much as one-half inch. This leads to violent straining and frequent leakage at the furnace mouths and other transverse seams of rivets. Many furnace-tubes though only five-sixteenth inch thick have stood a hydraulic test of 120 lb. per sq. in. without movement, and have worked satisfactorily for years at a steam pressure of sixty pounds. It is advisable however to have them a little thicker than this, in order to afford a margin for waste through corrosion, and also, when the flanged seam is adopted, in order to allow for the thinning that occurs in drawing the metal to make the flange. A thickness of three-eighth inch is sufficient for a working pressure of seventy-five pounds per square inch, thirteen-thirty-seconds inch for a pressure of eighty or ninety pounds, and seven-sixteenth inch for 100 lbs. per sq. in.

Stays are sometimes introduced for tying furnace-tubes to the outer shells in order to support them. Such stays however in the Lancashire boiler are unnecessary, and when rigid are decidedly objectionable. Furnace-tubes should be left free to move. As soon as a fire is lighted within them the top of the tube becomes hotter than the bottom and elongates. This makes the tube arch upwards. In conducting a series of trials in 1867 and 1868 for the South Lancashire and Cheshire Coal Association on the evaporative efficiency of their coals, and also on the comparative merits of different boilers, the writer had three-gauge rods attached to the crown of the furnace-tubes of two Lancashire boilers, and carried up vertically through the external shell by means of brass stuffing boxes, so that a ready opportunity was afforded of witnessing the rise and fall of the furnace-tubes; while as the gauge rods divided the tubes into equal lengths, a comparison could be drawn as to the movements of the different parts. Constant observation showed that the distortion of the tubes varied very much at different times, being most severe shortly after lighting the fires, while the colder the water to start with, the greater was the rise of the crown. As soon as the water became generally heated the gauge-rods retired to their old position, and the distortion of the furnace-tubes seldom lasted more than an hour. The boilers were twenty-eight feet long, the furnace-tubes of steel five-sixteenth inch thick in one case, and of iron three-eighth inch in the other. Care was taken not to strain the boiler by severe firing, steam being got up with the dampers only partially open. Yet the furnace-tubes rose three-eighth inch when the flames passed around the boiler in the external brickwork flues in the ordinary way, and one-half inch when they passed off direct to the chimney without heating the outer shell. The curve that the flue appears to assume is not a segment of a circle. The gauge-rod at a quarter of the length of the boiler from the front showed in one case as high a rise as the rod placed midway in the length of the boiler, and in another case one-sixteenth inch more. This is just what might be expected from the local action of the fire, and accounts for the grooving action being far more severe at the front end of a boiler than at the back, and shows the importance of affording greater elasticity at that part. Furnace-tubes lashed to the shell often tear themselves away from it in ordinary work, and the fractured stay rubbing against the shell leaves a witness of its movements, the amount of which frequently exceeds that just mentioned.

In one case a furnace-tube that had a stay tying it to the top of the shell was found to have crumpled up the stay and broken it by an upward thrust, showing how little need there had been for trying to keep the furnace-tube from drooping.

Shell.—The shell, which is seven-sixteenth inch thick for a pressure of seventy-five pounds per square inch, and nine-sixteenth inch thick for a pressure of 100 lbs., is composed of plates about three feet wide, which are laid in not more than three lengths round the circumference, in order that the longitudinal seams may clear the brickwork seatings. The longitudinal seams are so arranged as to break joint and avoid the center line along the top and bottom of the boiler. In all the longitudinal rents obtained under the experimental hydraulic tests, the plates bulged outwards at the middle of

their width, and this action was observed to a slight extent before rupture, showing that the greatest strain and thus the point of first fracture occurred at or near the center line of each plate. This would seem to show that breaking joint is of practical advantage, and that a boiler composed of wide plates is not so strong as one composed of narrow ones.

There is no steam dome. Steam domes are expensive, weaken the shell, and often give trouble from leakage at the base. Added to this they are inconvenient in carriage, as well as in revolving a boiler on its seat, as it is sometimes desirable to do for repairs; they are also inconvenient in covering the boiler over, and in the great majority of cases, if not in every instance, they are perfectly useless. To prevent priming, an internal perforated pipe is adopted in place of the dome. Under hydraulic pressure with a steam dome three feet diameter, seven-sixteen inch thick, and the whole of the shell plate at its base cut away so as to form an opening as large as itself, the flange at the base of the dome ripped at a pressure of 150 bl. per sq. in. At a second trial with a dome of the same diameter, and a portion only of the shell plate cut away, the dome strained so much round its base and caused such violent leakage that a pressure of more than 235 lb. could not be obtained. At a third trial, the steam dome having been removed and refixed with stouter rivet heads, so as to resist the upward strain that was induced, the flange at the bottom of the dome ripped on the center line of the boiler at a pressure of 260 lbs. per sq. in. In this instance the workmanship was all good and sound, but in some cases where domes are attached with inferior reedy angle-irons the weakening effect of the domes must be much greater. Steam domes clearly establish a weak point in a shell, and are better avoided.

The manhole is guarded with a substantial raised mouthpiece of wrought iron, welded into one piece, flanged at the bottom and attached to the boiler with a double row of rivets, the thickness of the upper flange being seven-eighth inch, and of the body three-quarter inch. This has been found to stand a test of 300 lbs. per sq. in. without the slightest indication of straining. A raised wrought-iron manhole mouthpiece is exhibited. It is too frequently the practice not to strengthen manholes with any mouthpiece at all. Many explosions have arisen from this cause, rents starting in the first place from the unguarded manhole, and then extending all over the boiler. The loss of strength is owing not simply to the amount of metal cut away by the opening, but also to the action of the cover, which in unguarded manholes is internal. This internal cover bears on a narrow edge of plating all round, and is driven outward by the pressure of the steam, and also pulled in the same direction by the bolts in tightening the joint. In fact the cover acts as a sort of mandrel, which being forcibly driven through the manhole splits the boiler open. A heavy hydraulic test shows this action of the cover, by curling the boiler plate up around the manhole. Added to this, the joint is apt to leak, and thus to induce corrosion and thin the plate, which not only reduces its strength but leads to extra force being applied to tighten the joint; several explosions have occurred shortly after the joint has been re-made. It has been the general practice till recently to make the raised mouthpieces of cast iron. This however is not wise for the high pressures now in use. A raised manhole mouthpiece having a clear opening of sixteen inches diameter, which is the usual size, involves a hole in the shell plate at its base of about twenty inches diameter. The plate in which this hole is cut, unless it be duly strengthened, becomes the weakest part of the boiler when the longitudinal seams are double-riveted, the furnace-tubes suitably strengthened with encircling rings, and the ends well stayed; so that the stability of the entire structure depends on the mouthpiece: if that fails, the whole structure fails. Under these circumstances it is evidently unwise to risk the safety of the boiler on a piece of cast iron. This view is confirmed by the behavior of cast iron manhole mouthpieces under hydraulic pressure. Several have failed under the ordinary test at the boiler-maker's yard, while at one of the experimental bursting tests a cast-iron manhole mouthpiece of substantial pattern, measuring one inch and seven-eighths thick in the lower flange and

one inch in the body, rent at a pressure of 200 lbs. per sq. in., though the metal exhibited a good sound fracture. This specimen is exhibited to the meeting. It would appear that under pressure there is a considerable upward strain on the plates around the mouthpiece; and that while wrought-iron mouthpieces are able to accommodate themselves to this without distress, cast-iron ones are not. These tests have shown that wrought-iron manhole mouthpieces are much superior to cast iron, and that the sooner cast-iron ones are generally superseded by wrought-iron the better.

The mudhole at the front of the boiler, beneath the furnace-tubes, is also fitted with a substantial mouthpiece. This in some cases is external, like the manhole mouthpiece, and in others internal. The internal ones have the advantage of being less in the way. In either case the surfaces at the joint between the body of the mouthpiece and the cover are faced true, so that the parts may be brought together metal to metal.

The safety-valves and steam stop-valve are sometimes grouped upon the manhole mouth-piece, instead of being fixed direct to the shell; this is done in order to reduce the number of openings, on the principle that the fewer holes made in a boiler the better. This argument is plausible but fallacious. The manhole makes the largest opening, and therefore exerts the greatest weakening effect. The weakest link in a chain is the measure of the strength of the whole; so that fixing the steam stop-valve and safety-valves directly to a boiler with suitable fitting blocks does not weaken it. Moreover, for convenience in attaching the fittings, these group manhole mouthpieces are made of cast-iron, which as already explained is objectionable. It is therefore recommended that manhole mouthpieces should not be complicated by the addition of the safety-valves or other fittings, but that each should be fixed direct to the shell independently of the others.

Blocks for the attachment of Fittings.—In old fashioned practice the fittings were bolted directly to the cylindrical portion of the shell. This led to the wasting of the shell through leakage at the joints; so that it has long since been the practice to rivet short stand-pipes to the cylindrical portion of the shell and bolt the fittings thereto, the joint surface between the flanges being planed up true. These stand-pipes, frequently termed "fitting blocks," are not only more convenient for the attachment of the fittings, but also, being riveted to the plate and made of substantial section, strengthen the plate round the hole cut in the shell. They are as a rule made of cast iron, but it becomes a question whether, with the high pressure now in use, they should not be made of wrought iron. At one of the experimental bursting tests, a fitting block for a six-inch steam valve box was found to give way before any other part of the boiler, at a pressure of 275 lb. per sq. in., though the flange was one five-eighth inch thick, the body seven-eighth inch and the metal sound.

Seams of Rivets.—Those running longitudinally in the cylindrical shell are all double-riveted, with three-quarter inch rivets spaced about two and a half inches apart longitudinally and two inches diagonally. The remaining seams throughout the boiler are single-riveted only, the rivets being spaced two inches apart. To double-rivet the transverse seams adds but little, if any, strength to the boiler, though it increases its weight and cost. It would appear that the strain upon the transverse seams of rivets in a Lancashire boiler is over-estimated. In a plain cylindrical boiler, without furnace tubes, the strain on the transverse seams of rivets is precisely half that on the longitudinal seams. By the introduction of the furnace-tubes not only is the longitudinal strength increased, but at the same time the area of the ends upon which the steam acts is diminished, and thus the strain is diminished also; so that in the Lancashire boiler the strain on the transverse seams of rivets is less than half that on the longitudinal seams. The force of this reasoning however is sometimes disputed, and tie rods are introduced to support the transverse seams of rivets in the shell. But in the hydraulic bursting tests, with the tie rods removed, the longitudinal seams of rivets were found to fail in every care before the transverse seams, which never showed the slightest signs of distress and scarcely leaked a single drop, while some of the

longitudinal seams under severe pressure shortly before rupture leaked profusely.

The riveting is done by machine in preference to hand in the cylindrical shell, in the furnace-tubes, and as far as practicable in the flat ends. In the experimental bursting tests, the machine work in every case proved much tighter than the hand work. The rivet holes in the angle irons, T irons, and flanged seams are drilled, those in the plates being punched by most makers; though by some the holes are drilled throughout, and the practice of drilling is strongly advocated by them. In investigating an explosion that occurred at Blackburn, in March, 1874, the mean tensile strength in twelve tests of a solid plate was found to be 21.19 tons per square inch, and in four tests of a punched plate 20.17 tons, showing a loss by punching of 1.02 tons per square inch, or about five per cent. The question of drilling versus punching, and also of the pitch and diameter of rivets, is one that deserves further consideration; and it may be added that a boiler seven feet diameter, and made of plates seven-sixteenth inch thick, having the longitudinal seams double-riveted with three-quarter inch rivets, spaced three inches apart longitudinally, instead of two and a half inches as usual, was found tight at a hydraulic pressure of 120 lb. per sq. inch. The edges of the plates at the longitudinal seams of rivets are planed and caulked lightly, inside as well as out; though in many cases caulking is superseded by fullering.

Material.—As a rule, boilers made under the inspection of the Manchester Steam Users' Association are of iron in the shell, while steel plates are very frequently introduced in the furnace-tubes for a length of nine feet over the fire, and sometimes from one end of the boiler to the other. For the furnace-tubes steel plates have been found to give great satisfaction, but a little suspicion has been entertained with regard to their use for shells, seeing that the plates are then in extension, and that a small flaw through brittleness might extend till it produced serious consequences. "Best best" plates from first-class makers are always recommended, more importance being attached to their ductility than to their tensile strength. Brands however are uncertain, and it is thought desirable that a complete system of testing should be adopted, and that, before a boiler is made, one plate out of the set proposed to be used should be tested as a check, the investigation having special reference to ductility. Low Moor rivets are recommended and are frequently used.

EQUIPMENT.

Fittings.—The fittings are so arranged that all those requiring frequent access are immediately within reach of the attendant when standing in front of the boiler. The feed is introduced on one side of the front end plate, about four inches above the level of the furnace crowns, an internal dispersing pipe being carried along inside the boiler for a length of about twelve feet, and perforated for the last four feet of its length. On the opposite side of the front end plate is fixed the scum tap, to which is connected a series of sediment-catching troughs fixed inside the boiler. In the center of the end plate are two glass water-gauges, one acting as a check upon the other, a pointer being fixed to show the correct height at which the water should be kept. Immediately above the water-gauges is a dial pressure-gauge, and above that a dead-weight safety-valve. Thus whenever the attendant opens the furnace doors to charge the fires, he has the height of the water and the pressure of the steam directly before him. Under his feet is the blow-out tap, and behind him the coal supply, so that everything is ready to hand. He has not to climb a ladder in order to reach the water-gauges or ascertain the steam pressure, nor to mount on the top of the boiler in order to regulate the feed supply. A handle for regulating the dampers is frequently brought to the boiler front. On the top of the boiler are two safety-valves, one a dead-weight valve of external pendulous construction, the other a low-water valve. But convenience in manipulation is not the only reason for this arrangement of fittings. If the feed be cold and be introduced near the bottom of the boiler, it is apt to induce local contraction, and thereby strain the transverse seams of rivets at the bottom of the shell; but when introduced near the surface of the

water and passed through an internal perforated pipe, it becomes dispersed before falling to the bottom. Further, although non-return valves may be introduced, they will sometimes fail and allow the water to escape, whereby the furnace crowns become bare and overheated. When the feed inlet is placed above the level of the furnace crowns, it will be seen that they cannot be drained bare by leakage at the non-return valve; but when placed at the bottom of the boiler, the boiler may then be emptied by such an occurrence.

All the joint surfaces are planed up true, and the parts brought together metal to metal. The edges of the flanges are turned, as well as the bolts, while the heads of the nuts are shaped, and the whole got up like a piece of engine work, as shown by the end plate and fittings exhibited.

Safety Valves.—The dead weight valve, which is of the Cowburn type, is extremely simple and efficient. The center of gravity of the load being below the seating renders unnecessary either wing or fang for keeping the valve in position, and it has therefore no frictional surface to get tight or stick fast. These valves are loaded with flat annular plates or rings, and the shell is cast with mouldings around it at the bottom which present the same appearance, the whole being so adjusted that each moulding as well as each annular plate represents a pressure of five pounds per square inch, on the valve. Large numbers of these valves are in use, and they are highly approved. The diameter generally adopted is four inches, which requires approximately a load of eight cwt. for a blowing off pressure of seventy-five lbs. and eleven cwt. for 100 lbs. per sq. inch. On this valve the addition of two or three bricks produces no appreciable effect, whereas at the end of a long lever the result would be different. To double the blowing-off pressure it would be necessary to add about eight cwt. to the load for seventy-five pounds, and eleven cwt. for 100 lbs. Such an addition there would be great difficulty in attaching to the valve, and if it were done it would be so conspicuous as at once to call attention to the fact. The great weight required to load this valve is considered therefore to be a safeguard: and several explosions due to over-loading have been met with, which would have been prevented by its use.

The low-water safety-valve shown is of the Hopkinson type; but there are also the Kay and the Lloyd low-water valves, which though varying in detail are similar in their object. Each has a lever inside the boiler, to which is attached a float, so that when the water falls below the desired level the float falls also, and thus raises the valve and allows the steam to blow off, thereby not only giving an alarm but also lowering the pressure. Hopkinson's valve is a compound one, having one valve seated on another; the central portion is loaded by a dead weight inside the boiler, and operated upon by the lever in the event of low water, while the annular portion is loaded by an external lever and weight, and lifts along with the central portion in the event of high steam; these valves therefore blow off on the occurrence either of high steam or of low water. The outer valve is five inches diameter, and the inner one two and a half inches. The freedom of the steam valve can be tested by placing the hand on the lever when steam is up; while the freedom of the low-water apparatus can be tested by opening the blow-out tap and lowering the water-level to within about six inches of the furnace crowns. To overload this valve without increasing the weight outside would necessitate getting inside the boiler and wedging down the dead weight. Under such circumstances the application of the hand to the external lever when steam was up would at once show that something was wrong; and even if this were not detected the external dead-weight valve if free would come to the rescue, while it would be seen at at a glance whether this was overloaded. It is sometimes recommended to have safety-valves under lock and key, but it is preferred by the writer to have them thoroughly open, so that their publicity may be their protection. While it is fully admitted that no arrangements of safety-valves can be contrived which cannot be tampered with by skilled malice, it is thought that the combination of the two valves just described forms a very safe arrangement.

Furnace Mountings.—The furnace

mouthpieces are of wrought iron, finished off with a neat brass beading, and kept within the circle of the rivets, so as to leave these exposed to view. The fire-doors are fitted with a sliding ventilating grid on the outside and a perforated box baffleplate on the inside, the aggregate area of the air passages being about fifty sq. in. for each door or about three sq. in. per sq. ft. of firegrate. The firegrate is six ft. long, with the bars in three equal lengths, about three-quarter inch thick, and spaced three-eighth inch apart for windage. The bearers consist of two wrought-iron bars carried on wrought-iron brackets riveted to the sides of the furnace-tubes. The standard length of grate is six ft., but a shorter one is productive of economy, though the concentration of the fire is more trying to the boiler, and has been found, where the feed water has not been good, to injure the furnace plates, and render it necessary to lengthen the grate.

SETTING.

Brickwork and Flues.—The boiler is set on side walls, and rests on firebrick seating blocks presenting a bearing surface of five in. wide. The side flues are six in. wide at the top, carried up to the level of the furnace crowns or a few inches above, and down to the level of the bottom shell. The bottom flue has a width equal to the radius of the boiler, and a depth of about two ft. These dimensions admit of ample room for inspection. By keeping the width of the bottom flue equal to the radius of the boiler, the angle that the bearing surface of the seating block makes with the horizon is thirty degrees for any diameter of shell.

The flame immediately after leaving the furnace-tubes passes under the bottom of the boiler, and returns to the chimney along the side flues. This is not the course approved by Mr. Pole in his treatise on the Cornish Pumping Engine, published in "Tredgold on the Steam Engine" in 1844, in which the setting of the Cornish boiler is spoken of as follows:—"The heated current first impinges on the top of the tube, over which the highest and therefore the hottest portion of the water is lying; it then passes along the side flues, where it finds the surfaces cooler than before; and last of all it traverses under the bottom of the boiler, where the coldest water will always be. . . . . By this means the fire current, as it gradually cools, is likewise gradually brought to to act upon cooler water, and thereby the best opportunity is afforded for the extraction of the free caloric it contains. The descending motion of the fire current, as it cools in the flues of the Cornish boiler, is upon statical principles much more natural and more calculated to prevent the unnecessary discharge of heat into the chimney than the ascending principle of the ordinary boilers." Allowing the last heat however to travel under the bottom of the shell does not promote the circulation of the water, or at all events but slowly; so that in getting up steam the top of the boiler becomes hotter than the bottom, from which straining ensues. If in addition to this, the feed water when cold be pumped in at or near the bottom of the boiler, the straining at the transverse seams of rivets is intensified. Possibly the Lancashire boiler is more subject to straining and seam-rending at the bottom of the shell than the Cornish, as there is a greater body of dead water lying there in the Lancashire boiler, in addition to which the rate of combustion per square ft. of firegrate is much more rapid in the Lancashire district than that generally adopted in Cornwall. In consequence of seam rents occurring at the bottom of Lancashire boilers when the last heat is carried underneath, the plan of passing the flame under the bottom immediately on leaving the furnace-tubes, and also of introducing the feed water near the surface, has become the general practice. The question of economy is met by the use of feed-water heaters, consisting of a number of water pipes placed in the main flue between the boiler and the chimney, and kept free from soot by an automatic scraper. A good feed heater will raise the temperature of the water to about 240°. This answers two good purposes: it economises the waste heat escaping to the chimney and thus reduces the coal consumption, while at the same time it prevents local cooling, thereby preventing straining and saving repairs. It has been found by experiment that passing the flames from the furnace tubes around the outer shell, instead of

direct to the chimney, adds but little to the yield of steam, though it promotes economy of fuel: at the same time it keeps the boiler at a more equable temperature throughout.

The flooring or hearth plates at the front of the boiler are set so as not to butt against the boiler, which is too often the case, but so as to be entirely below it, thus leaving the whole of the front end plate open to view. Where there is a range of boilers, these flooring plates extend throughout the width of the boiler house and being finished off with a fender-flange where abutting against the boundary walls of the building, as well as against the face of the brickwork setting, they present a very neat appearance. These plates are carried on a complete system of framing, and are arranged for easy lifting. The hearth pit beneath them is open from one side of the boiler house to the other, and in this is laid the main feed-pipe, as well as the discharge pipe from the blow-out and scum. This pit is about three feet wide by two and a-half feet deep, so as to afford room for access; the flue doors open into it. The face of the brickwork at the front of the boilers is set back six inches, so as to leave the angle-iron with its circle of rivets perfectly open. The front cross wall beneath the boiler is recessed around the blow-out elbow-pipe, so that it may be free to move should settlement of the boiler take place.

Boiler Covering.—The boiler is covered with an arch of brickwork, leaving a space of about two inches between it and the plates; and a layer of cork shavings or a coating of good boiler composition or other suitable non-conducting substance is introduced into this space. Openings finished off with bull-nosed bricks are worked round the fittings, so as to leave the ring of rivets by which they are attached to the shell exposed to view. Sometimes the boiler is covered simply with a layer of composition, which should not be carried over the flanges of the fittings, as is too often the case, but should be stopped off by means of kerb hoops dropped around the flanges, and a kerb cast-iron nosing to guard the front angle-room.

Connections.—All connections to boilers should be elastic, so as to allow of their movement. If the main steam-pipe be carried across the boilers and bolted direct to the steam junction-valve, the joints are strained by the rising and falling of the boilers as they are set to work or laid off. To prevent this, a springing length should be introduced between the stop-valve and main steam-pipe. Where the main steam-pipe has a considerable length to travel to the engine, it should not be taken in a direct line, but should either be carried round the boiler house or be led in a horse-shoe shaped course, to give elasticity; this is better than introducing an expansion joint, which is not reliable. Sometimes expansion diaphragms are adopted; but these, when as much as four feet diameter, have been known to lead to the fractures they were intended to prevent; the internal pressure causing them to bulge outwards, when it was expected that they would allow the pipes to expand and thrust them inwards. A case of this sort has recently come under the writer's knowledge, in which the main junction-valve was broken off by the thrust occasioned by the bulging of the expansion diaphragm. It is equally important that the feed connection should be elastic; and from the want of elasticity, feed-valve boxes have been known to fracture. For this purpose a copper elbow connecting-pipe is introduced between the main feed-pipe and the stand-pipe; in some cases a wrought-iron horse-shoe shaped pipe has been adopted instead, with very satisfactory results.

Connections between the steam stop-valve and main steam-pipe are frequently made to incline upwards, so that the water may drain back to the boilers. This plan, however, is objectionable; for when one of the boilers in a range is laid off, the connecting length becomes filled with water from condensation of the steam, which, cooling by radiation, sets up a violent conflict with the steam, whereby the pipes are sometimes fractured. The action may be illustrated by the commotion which occurs within a locomotive tender when the steam from the boiler is turned into it. Further than this, on opening the steam stop-valve of a boiler that has been laid off, the water lying on the top of the valve is apt to be carried forward by the rush of steam, like a water hammer, and sometimes to burst the pipes. To pre-

vent this, the steam-pipe should drain towards the engine, and not towards the boiler, its course being intercepted by a separator fixed as near the engine as convenient. The principle on which these separators act is that of making the steam take a sharp turn, so as to shoot off the water mixed with it into a catch-chamber prepared for the purpose. Many of these separators are now at work; the principle was advocated by Dr. Haycraft, of Greenwich, five-and-twenty years ago.

Weight and Cost.—The weight of such a boiler as has now been described is about twelve tons without fittings; with fittings, fifteen and a-half tons. The cost at the present time, delivered on the premises of the purchaser within a few miles of Manchester, and including the attachment of the fittings, is about £450. The plan of buying a boiler at so much per ton, and then the fittings at so much extra, is quite given up in favor of purchasing the whole for one sum.

Heating Surface.—Such a boiler has a heating surface in the external shell of 370 square feet; in the furnace-tubes, without water pipes, 450 square feet; in the water pipes 30 square feet: making a total of 850 square feet. The firegrate has an area of thirty-three square feet; this gives for every square foot of firegrate twenty-six square feet of heating surface. The surface in feed-water heaters varies; sixty pipes, each affording a heating surface of about 10 sq. ft., are now frequently introduced per boiler, making a total heating surface of 600 sq. ft., or about three-fourths of that in the boiler.

Working Results.—Such a boiler as that described will burn, without distress to the boiler, from fifteen to twenty tons of coal in a week of sixty working hours, or from seventeen lbs. to twenty-three lbs. per square foot of firegrate per hour. This may be done without making smoke; all that is needed is to maintain a good thickness of fire, throw on the coal little and often, admit a little air above the bars for a short time after firing, and avoid the use of the rake. The coal may either be spread over the whole surface of the fire or thrown at alternate firings first to one side of the furnace and then to the other, on the "side firing" system introduced by Mr. Charles Wye Williams.

A Lancashire boiler experimented on at Wigan, with furnaces two feet seven and a-half inches diameter and a firegrate four feet long, evaporated 83.54 cubic feet of water per hour, from a temperature of 100° Fahr., at the rate of 10.44 lbs. of water per lb. of coal, when burning twenty-four lbs. of coal per square foot of firegrate per hour. With a firegrate six feet long it evaporated per hour 98.58 cubic feet of water at the rate of 10.37 lbs. of water per lb. of coal, and burnt nineteen lbs. of coal per square foot of firegrate per hour. These results were obtained at atmospheric pressure, with the help of a water heater, with good round coal and without making smoke. The boiler described in this paper, having furnaces two feet nine inches diameter, would evaporate a larger quantity of water per hour. Such a boiler is found in practice to be capable, provided the steam be applied to a fairly economical engine, of developing 200 Ind. H. P. per hour, and twenty Ind. H. P. per lineal foot of boiler frontage, side flues included. A Cornish boiler under similar conditions is capable of developing sixteen Ind. H. P. per foot of boiler frontage. This leads to a question of the utmost importance, namely the one which the late Mr. Robert Stephenson defined as the "administration of the steam;" and fuller information is yet needed as to the comparative advantage of working steam on the compound or single-cylinder principle; also as to the value of steam-jackets, as well as with regard to the initial and terminal pressures most conducive to economy. These inquiries, though full of interest, cannot be entered upon in the present paper; but one of the essentials to economy is the power of raising high-pressure steam steadily and safely, and this may be accomplished by the use of the Lancashire boiler.

ACCORDING to *Herapath* the amount of taxation collected by the French Government from French railway traffic last year was £3,650,799. The corresponding collection in 1874 was £3,281,895. Rather more than two shillings out of every pound sterling acquired upon the French lines is handed over to the French Treasury for the purposes of the Republic.

THE STRUCTURE OF STEEL.

From "Engineering."

THE practical experience of the past ten years or so has undoubtedly added vastly to our knowledge of the manner in which steel can be best turned to account as a structural material, but it is equally true that while we have learned that the presence of certain materials in steel is deleterious, and that certain modes of treatment produce beneficial effects, we have as yet learned little as to the reasons for these results. Take for instance the practice of oil-tempering as now applied at Woolwich to the steel tubes used for lining guns, or the rapid cooling in water as they come from the rolls of steel plates for locomotive fireboxes, as carried out at Crewe and elsewhere; both these processes, as is well known, improve the quality of mild steel, yet so far no theory has been generally accepted as accounting for the results obtained. So also it is well known that steel ingots, when forged or rolled, have at first to be be treated very carefully; but that after having been lightly dealt with under the hammer or in the rolls, they will gradually bear more and more severe treatment, and this although the finished bar is practically identical in chemical composition with the original ingot. This alteration of the character of steel under the action of forging or rolling has probably attracted less attention than it otherwise would, from the fact of the effect produced so strongly resembling that which occurs in the manufacture of wrought iron. Yet if we examine the two cases we shall see that they are by no means parallel. A puddled ball, as first placed under the hammer, is a mass permeated in every direction by slag which separates the particles of iron, and in the operation of shingling this slag is more or less thoroughly expressed and the particles of iron welded together. In the case of a steel ingot, on the other hand, cavities and cracks may exist, it is true, but the interruption of continuity of the metal caused by these cavities is in no way comparable to that due to the presence of the slag in a puddled ball, and the "tenderness" of steel ingots must therefore be traced to some other cause. In seeking for this cause it must be borne in mind, moreover, first that cast ingots which are practically solid still exhibit "tenderness" at first under the hammer, and, secondly, that the specific gravity of cast steel is not increased, but in some cases slightly diminished by the process of forging.

Although, as we have said, there is as yet no theory generally accepted as accounting for the above-mentioned facts, and although they have not been so extensively investigated by those practically engaged in the steel manufacture as their interest would seem to warrant, yet explanations of them have not been entirely wanting. Amongst these is one to which we now wish to direct special attention, believing, as we do, that it is worthy of very attentive consideration. The explanation in question is that offered as long ago as 1868, by M. Chernoff, in some papers contributed to the Russian Technical Society. M. Chernoff is the assistant manager of the well-known Abouchoff Steel Works, near St. Petersburg, and he has thus had an extensive experience with steel forgings of large as well as small dimensions, so that his opinion possesses considerable weight. This being so, it is somewhat singular that the theory which he advanced eight years ago—strongly supported as it is by facts—should have hitherto received so little attention, either in this country or abroad. Now, however, we are glad to say, Mr. W. Anderson, of the firm of Eastons and Anderson, has translated M. Chernoff's memoir into English and has had it printed in pamphlet form. By the courtesy of Mr. Anderson, we shall in an early number be enabled to reproduce M. Chernoff's paper *in extenso*, when our readers will be able to judge for themselves of the theory which he so ably advances; in the mean time, however, we propose to state the outline of that theory, and to make some remarks upon points suggested by it.

Passing over some interesting remarks made by M. Chernoff respecting the high

quality of Eastern Steel known as "boulat," and the facts he adduces to prove that the various markings of this and similar steels is not due to the admixture of foreign substances, but to the structure of the steel at different points, we will proceed at once to the theory which M. Chernoff advances to explain the changes which take place in steel during the operations of forging and tempering. M. Chernoff holds that in a compound of iron and carbon such as steel is, the carbon may be regarded as occupying the same relation to the iron that the water of crystallization of a salt does to a salt when in the form of crystals. If a crystalline salt, such as alum, be placed in a suitable vessel and gradually heated, a temperature will at length be reached when the crystals will begin to coalesce and contract, the whole will become fluid, the salt being at this higher temperature completely dissolved in its water of crystallization. Just in the same way M. Chernoff considers the iron of steel may be supposed at a certain temperature to become dissolved in the carbon which is associated; there thus resulting a fluid mass which may be presumed to be subject to the same laws as those which govern such a molten crystalline salt as we have just referred to.

But we know that if a crystalline salt which has been sufficiently heated and thus dissolved in its water of crystallization, be subsequently allowed to cool, crystallization will again take place, the character of the crystals formed, however, being influenced by the treatment which the solution undergoes during this cooling. For instance, gradually cooling and the maintenance of the solution in a quiescent state will result in the formation of large, well-developed crystals, while agitation during this slow cooling, or rapid cooling without agitation, will cause the formation of small crystals. Finally, the combination of agitation with rapid cooling will interfere still more with the crystalline formation.

More than this, it will be found that not only can the formation of large crystals be prevented by agitating the solution while only fluid, but that even after the commencement of crystallization disturbance of the particles will cause the crystals to be redissolved, the effect of the agitation being thus to reduce the temperature at which the crystals will remain in solution.

Now M. Chernoff shows that in its behavior steel is strictly analogous to the solution of the crystalline salt in its water of crystallization, and the experiments he quotes to prove this are of exexceptional interest. Briefly stated, the facts which he adduces are as follows: Up to a certain temperature (which will vary in different samples, and which M. Chernoff denotes as the point *a*), steel may be heated and subsequently rapidly cooled, as for instance by dipping in water, without producing any hardening effect; on the contrary, it will become softer and more easily worked. If, however, the temperature *a* be exceeded, then the rapid cooling will be accompanied by hardening. At a temperature that is higher than *a*, not by a strictly defined amount, but by an amount which is variable in different qualities, the steel begins to alter its structure, and between this point of change (which M. Chernoff denotes as *b*) and its melting point, it gradually passes from a crystalline to an amorphous condition. If, on the other hand, a mass of steel is cooled down quietly from the molten state, it will, by the time the temperature *b* is reached, have assumed a crystalline structure, and this structure will not change during the further cooling, while after passing the temperature *a* it will not harden, however rapidly the reduction of temperature may be effected.

Bearing in mind what has been already stated respecting the behavior of a crystalline salt when dissolved in its water of crystallization it will be seen that presuming the analogy between such a salt and steel to be correct, the treatment which the latter should receive to prevent the formation of a coarsely crystalline structure is plainly pointed out. What is needed is, that when between the melting point and the temperature which M. Chernoff denotes as *b*, the particles of the metal should constantly be kept in a state of disturbance, as is practically the case when a mass is being forged, or that the temperature should be reduced so rapidly as not to permit of the formation of large crystals. Practically, the operation of forging

or rolling are usually necessary for mechanical reasons, and it is by such operations therefore that the formation of a coarse crystalline structure can generally be best prevented, but it is to be borne in mind that to be thoroughly beneficial this forging or rolling must be continued until the temperature of the metal has fallen to the point *b*, or otherwise crystallization will proceed after the mechanical treatment. It is remarked by M. Chernoff that it is only when the temperature has fallen below *b* that the density of steel can be increased by forging. For such steels as are used for larger ingots, however, the temperature *b* is so low comparatively, it being only about a dull red heat, that below it no existing hammers are sufficiently powerful to deal with large masses. Small forgings may, however, be dealt with at a lower temperature, and the results are in some respects remarkable.

As regards the mode of arresting the formation of large crystals by a rapid cooling of the metal from a temperature above the point *b*, although for mechanical reasons not generally applicable as a substitute for forging or rolling, yet it is undoubtedly a mode of treatment which forms an important auxiliary, constituting as it does, to some extent, a means of correcting insufficient forging. Thus, if the process of forging has been resorted to only to give the required shape and has not been continued until the mass has fallen to the temperature *b*, crystallization will, as we have stated, ensue; but this crystalline structure can be changed to an homogeneous one by re-heating the forging to a temperature somewhat above *b*, and then subjecting it to rapid cooling. The tempering in oil of the gun tubes at Woolwich, and the practice of repeatedly heating steel plates and then dipping them in water as adopted at Crewe, are instances of the practical application of the principles which M. Chernoff has enunciated. In fact these modes of treatment of steel forgings, &c., are specially recommended in his memoir, written, as it was, in 1868, and they are adopted on a large scale at the Abouchoff Steel Works.

M. Chernoff's paper was read before the process of compressing fluid steel had attracted any particular attention, or otherwise he would probably have alluded specially to this mode of treatment. As it is, the theory of M. Chernoff appears to throw a remarkable light on the results which Sir Joseph Whitworth has obtained. As long ago as 1861, Professor James Thomson experimented on the influence of pressure on crystalline solutions, and the result obtained corroborated the conclusions at which he had previously arrived on theoretical grounds that the application to a solid of stress of any kind other than hydrostatic must have the effect of lowering the melting point of that solid, and in the *Proceedings of the Royal Society*, for December, 1861, he remarks that "stresses tending to change the form of any crystals in the saturated solutions from which they have been crystallized, must give them a tendency to dissolve away, and to generate, in substitution for themselves, other crystals free from the applied stresses or any equivalent stresses." Applying Professor James Thomson's conclusions to the view of the structure of steel advanced by M. Chernoff, we thus see that there is good reason to believe that the effect of heavy pressure, such as is applied by Sir Joseph Whitworth to molten steel, may not consist merely in the mechanical closure of cavities which would otherwise exist in the mass when solidified, but that such pressure may in addition produce a more or less decided effect upon the structure of the metal after solidification. So far as we are aware Sir Joseph Whitworth has never made public any facts which would enable the suggestion here made to be verified or controverted, but the matter appears to us worthy of further investigation by those who have the means at their command.

Altogether we do not hesitate to regard M. Chernoff's paper as one of the most interesting and suggestive which has for a long time past come under our notice, and considering the important practical bearing of the facts which it adduces we think that our iron and steel manufacturers are greatly indebted to Mr. Anderson for the trouble he has taken in preparing and placing at the service of the public his able translation.

COMPUTATION OF EARTHWORK.

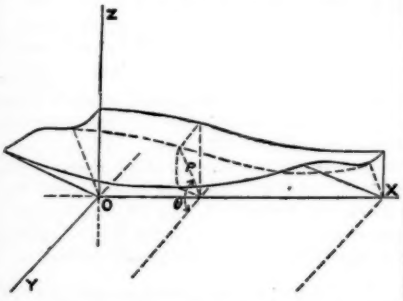
By Prof. E. W. HYDE, A. M.

Written for Van Nostrand's Magazine.

The Prismoidal Formula is the basis of the methods generally given in books on earthwork computation for ascertaining the volume of cut or fill when the center heights and transverse slopes at the ends of the section are different.

Not having seen any complete investigation of the limits of application of this formula, and of the nature of the surface to which the ground must approximately conform, if the result is to be accurate, I was led to look into the subject, and have published in the July number of the *Analyst* a mathematical investigation of the limits of this formula, and also of that of Weddle, which appears to be preferable in many cases to the prismoidal, both in point of accuracy and economy of time.

In the present paper the results obtained will be applied to the computation of railroad cut and fill and borrow-pits. In the article above referred to, it is shown that for the wedge-shaped solid, shown in the figure, the prismoidal formula holds exactly when the upper surface is represented by the equation,

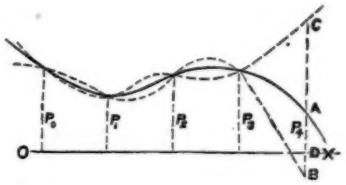


$$P^2 = x^2 f_1(\theta) + x^2 f_2(\theta) + x f_3(\theta) + f_4(\theta) \quad (1)$$

in which $f_1(\theta)$, $f_2(\theta)$, &c., are arbitrary functions of θ, the axis of x is the intersection of the side slopes, P is the distance from X measured perpendicularly to X, and θ is the angle between P and the horizontal plane X Y. If there be in the equation of the surface a term of the fourth degree, $x^4 f_0(\theta)$, there will be an error in the application of the formula of $\frac{1}{180}$ of the volume represented by the integration of this term.

In (1) let $x = n a$, then the equation represents some curve in a plane parallel to the end section, *i. e.*, perpendicular to X, and since the different functions of θ are arbitrary, the curve may be of any nature, and may be made to pass through any number of points in the plane $x = n a$. Thus the nature of the *cross-sections* of the ground surface is a matter of entire indifference so far as the application of the formula is concerned.

Now, suppose in eq. (1) that θ = constant, then we have an equation of the third degree in P and x representing a curve lying in a plane passed through X, *i. e.*, the intersection of the side slopes. Since (1) now contains four arbitrary constants, we can make this curve pass through any four points. Also, since P is of the second degree, it appears that the curve is symmetrical about X. In the figure, let P_0, P_1, P_2 and P_3 be four



given ordinates, and let the curve drawn full be the third degree curve fixed by their extremities. It cuts the ordinate P_4 at A. If A D is really the length of the next ordinate to the section of the ground surface, then the section must agree very closely with the mathematical third degree curve, provided that the curvature of the ground surface is tolerably regular. If, however, the section of the ground surface cuts P_4 at some point B or C below or above A, the curve will vary as in the figure, and will approximate towards a fourth degree curve. The curve through A has but

one point of inflection between P_0 and P_1, while those through B and C have each two, showing them at once to be of the fourth or a higher degree. It appears then that if equi-distant ordinates be drawn to the median profile, and any five consecutive ones be taken such that the curve (profile) between the first and fifth has not more than *one* point of inflection, the portion of the curve between the second and fourth ordinates will not differ very greatly from a third degree curve drawn through the extremities of the first or last four ordinates. If the ground surface is such that the same holds with reference to profiles taken on either side of the median line, as will generally be the case, then we can assert that the prismoidal formula will give very approximately the volume of the solid between the second and fourth ordinates to the median profile. If the common distance between P_0 and P_1, P_1 and P_2, etc., is 100 feet, we have whole sections, and the cut and fill can be computed more accurately as well as more expeditiously, when the above conditions of curvature are fulfilled, by taking *two sections at a time* and using the end areas as actually computed in the formula, than by taking only one section and finding the mid-cross-section by regarding the median profile and intersections of the surface with the side slopes as right lines, as is commonly done.

Weddle's Formula.—This formula requires seven equi-distant cross-sections. It is as follows:

$$V=\frac{3a}{10}[A_0+5A_1+A_2+6A_3+A_4+5A_5+A_6] \quad . \quad . \quad (1)$$

in which a is the distance between two consecutive cross-sections.

In the article above referred to it is shown that this formula holds exactly for the surface represented by the equation,

$$P^x=x^m f_0(\theta)+x^{m-1}f_1(\theta)+x^{m-2}f_2(\theta)+\&c. \quad . \quad (2)$$

when $m=5$, while if $m=6$, there is an error of $\frac{1}{1111}$ of the volume represented by the integrals of the terms of the sixth degree; and, if $m=7$, there is an error of $\frac{1}{1111}$ of the volume represented by the integrals of the terms of the seventh degree, in addition to the preceding. By means of the calculus of Finite Differences, however, or by elimination by the aid of determinants, the remarkable fact may be shown that, if a certain correction be subtracted from the formula in question such as will make it exact when $m=6$, *it will also make it exact if* $m=7$, the reason being that the correction for terms of the seventh degree cancels out, *i. e.*, becomes equal to zero. This correction is

$$\frac{a}{140}[A_0-6A_1+15A_2-20A_3+15A_4-6A_5+A_6], \quad . \quad (3)$$

or approximately,

$$0.007\,a\,[A_0-6A_1+15A_2-20A_3+15A_4-6A_5+A_6] \quad . \quad (4)$$

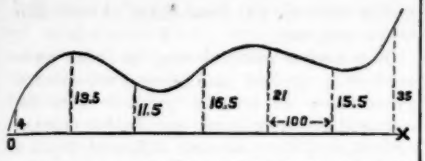
If (3) be subtracted from (1) we get a formula exact for the case when $m=7$, but the coefficients are so large that it is inconvenient to use, and we shall show that in many cases the value of (3) is very small, and shall indicate the manner in which we can decide from the form of the longitudinal sections whether the correction is large enough to make a serious difference in the result. If in eq. (2) we make $\theta=$ some constant, we have a section of the surface by some plane through X, its equation being of the form

$$P^x=Ax^m+Bx^{m-1}+Cx^{m-2}+....K.... \quad (5)$$

The curve represented by this equation is symmetrical about X, and cannot have more than $m-2$ points of inflection on the same side of this axis. When $m=5$, therefore, there can be but three such points, and this affords a criterion by which to judge of the degree of approximation of the longitudinal sections of our surface to fifth degree curves.

As the prismoidal formula and that of Weddle apply equally well to the problem of finding an area like that in the figure, the former then becoming Simpson's rule, we will take this case for our computation. A_0, A_1, etc., will then represent the ordinates to the given curve.

Let us assume a curve having only three inflection points between the ordinates at O and X, and let us obtain the area between these ordinates, the right line O X and the curve. Let $a=100$.



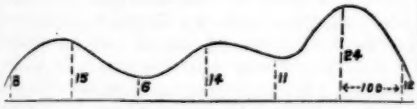
$\therefore$ the area $= 30\,[4 + 97.5 + 11.5 + 99 + 21 + 77.5 + 35]$
$= 30 \times 345.5 = 10365.$

Now let us find the value of the correction

(3.) It is $\frac{5}{7}\,[4 - 117 + 172.5 - 330 + 315 - 93 + 35] = -\frac{5 \times 13.5}{7}$
$= -9.64+.$

$\therefore$ Corrected area $= 10365 - (-9.64)$
$= 10374.64.$

The ratio of the correction to the whole area is about $\frac{1}{1076}$; so small that it may be disregarded in earthwork computations. Now let us take a curve with *four* points of inflection.



Area $= 30\,[8 + 75 + 6 + 84 + 11 + 120 + 12]$
$= 9480.$

Correction $= \frac{5}{7}\,[8 - 90 + 90 - 280 - 165 - 144 + 12] = -\frac{5 \times 239}{7}$
$= -170.7+.$

$\therefore$ Corrected area $= 9480 + 170.7 = 9650.7,$

and the ratio of the correction to the whole area is about $\frac{1}{56}$; more than nineteen times larger than in the previous case. The values of the ordinates in these two cases have been taken entirely at random.

It is evident that if some of the ordinates had been taken different, the amount of the correction might have been considerably changed. For instance, if the middle one had been 2 instead of 14, the correction would have been only $\frac{5}{7} = 0.714+$, but then the curve would have had only *two* points of inflection instead of four.

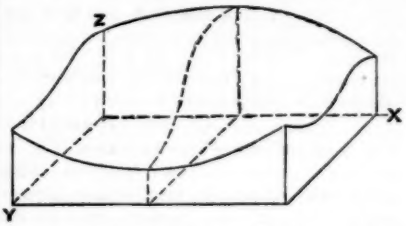
Since the application of the correction (3) renders the result exact when $m=7$, it follows that by using it a pretty accurate result may be obtained even when there are *five* points of inflection between the extreme ordinates of the longitudinal sections.

SOLIDS BOUNDED LATERALLY BY VERTICAL PLANES.

If, as in the figure, the ends are parallel and perpendicular to the sides which are also parallel, the prismoidal formula holds when the equation of the upper surface is

$$Z = x^m f_0(y) + x^{m-1} f_1(y) + x^{m-2} f_2(y) + (5)$$

so long as m is not greater than 3.



Similarly the formula of Weddle holds for the surface represented by this equation when m is not greater than 5, and, by applying the correction (3), when $m=7$.

Thus, as before, sections perpendicular to X may be of any nature whatever.

Suppose it were required to find the contents of the solid contained between a given area of earth-surface and a given horizontal plane. Let the area be laid off in squares of 25, 50, or 100 feet, according to the roughness of the ground and the accuracy required. Suppose we say 50 feet; then for the application of Weddle's formula take a strip 300 feet wide and as long as we please.

A_0 5	A_1 6	A_2 8	A_3 10	A_4 15	A_5 9	A_6 8
6	7	7	8	10	6	3
8	9	8	7	6	4	1
10	12	13	11	8	5	4
11	14	12	10	6	4	7
9	10	9	7	4	5	9
6	7	9	10	9	11	15

In the figure a square of 300 feet has been taken, the numbers at the corners are the heights above the datum plane, and the following is the computation:

$$\frac{3a}{10}=\frac{3\times 50}{10}=15 \therefore V=15\,[A_0+5A_1+A_2+6A_3+A_4+5A_5+A_6]$$

$$A_0=15\,[5+30+8+60+11+45+6]=15\times 165=2475$$

$$5A_1=75\,[6+35+9+72+14+50+7]=75\times 193=14475$$

$$A_2=15\,[8+35+8+78+12+45+9]=15\times 195=2925$$

$$6A_3=90\,[10+40+7+66+10+35+10]=90\times 178=16020$$

$$A_4=15\,[15+50+6+48+6+20+9]=15\times 154=2310$$

$$5A_5=75\,[9+30+4+30+4+25+11]=75\times 113=8475$$

$$A_6=15\,[8+15+1+24+7+45+15]=15\times 115=1725$$

$$\therefore V=15\times 48405$$

$$=726075 \text{ cub. ft.}$$

$$=26891.66 \text{ cub. yds.}$$

If the number of squares in the direction in which the areas are computed be not a multiple of 6, the remainder, after dividing by 6, may be calculated by Simpson's rule; directly if the remainder be even, and by interpolation of ordinates if it be odd. If, in the example computed above, the areas of the horizontal rows be taken instead of the vertical, the resulting volume will not be changed. If the computation be corrected by formula (4) it will be found that the result is about forty-two cubic yards too small, less than $\frac{1}{600}$ of the whole amount.

The above method may be very conveniently applied to the case where any given area of uneven ground is to be reduced to a uniform grade, horizontal or inclined, or to several different grades in different portions. In any case the process would be as follows:

Take a horizontal datum plane through the lowest point of the given area, and calculate as above the quantity of earth between this plane and the ground surface. This is the mass which we have to put into a new shape. Next, taking a horizontal plane through the lowest point or line of the proposed grade or set of grades, compute the volume between this plane and the grade surfaces. If this amount is *less* than the other take the difference and divide it by the area of the field to be graded, the quotient will be the height of the second datum plane above the first. Then by the principles of Topographical Projections, the lines of intersection of the grade surfaces with the original ground surface can be found, which will be the boundaries of new areas whose volume must then be computed as before. The portions above the grade surfaces will have the same volume as those below, so that only one set would have to be computed, unless, indeed, some allowance be made for the shrinkage of newly moved earth.

If the second of the two volumes first computed be the *greater*, then the grading will have to be carried below the lowest point of the natural surface of the ground, or else some change must be made in the arrangement of the grades.

THE ECONOMY OF FUEL—EXPERIMENTS ON A BOILER AND A STEAM ENGINE 110-HORSE POWER, MADE AT MAESTRICHT.

By L. LHOEST.

From the "Universal Review of Mining."

I.

The saving of fuel considered in its general aspects, or more particularly in its application to mechanical purposes, presents one of the most important questions of the age; and this importance increases day by day under the influence of the continued augmentation in the price of combustibles and the sub

stitution of machinery for physical labor. It is not astonishing that the investigation of this question has already produced numerous and elaborate works, the importance of many of which have, we think, been somewhat underrated by contemporary reviewers. The attention given to this subject by philosophers and experimentalists, amongst whom we may cite Hirn, Burnat, Leloutre, Schreurer-Kestner, and Groseteste, must not be forgotten, and their example has induced the undertaking of several experimental researches, the result of which it is proposed to communicate to our readers. It will be at once again seen by this paper how much may be justly expected from the progress of mechanical science already apparently so advanced; and it will also be seen by how much we must lessen our admiration at the sight of those powerful engines which set our workshops going with such facility and apparent perfection. In fact, what have we learned during these last few years? Simply this: that our best steam engines utilize scarcely one-eleventh of the power contained in the coal, the getting of which costs so much labor.

Since the fact of the unity of the natural forces of nature has been established, and also the relative bearing existing between heat and effective power, there no longer exists any doubt on the verdict of science. Fortunately, however, whilst science herself, thus seems to point to our impotence with a sort of defiance, she also shows to us the desired end, and indicates the means we should put in operation to attain it. Some of these means have been made use of in the description about to be given of an engine recently erected, and although its general arrangement is one productive of remarkable economy, less reliance will be placed on this fact than on the method of experimenting which has been followed. Accuracy in measuring and counting, and the make up of the total losses sustained, have been the principal objects kept in view, and the further knowledge will doubtless naturally follow.

The engine about to be described is one from the factories of the house of Gilain de Tirlemont, known, especially of late years, as well for the excellence of its machines as for the continued efforts made to improve them. The one in question comprises a group of several twin boilers and an engine of 110-horse power, and the following paper will be found divided under the following heads: (A.) Description of the heating apparatus, and the means of observation used; (B.) Summary thereof; (C.) Results obtained, and a concise analysis thereof.

(A.)—DESCRIPTION OF THE HEATING APPARATUS.

The steam generators consist of cylindrical boilers of the tubular type, externally fired, and super-heaters—the total heating surface, including the lower tubes, being 115 square meters, or about 1200 square feet, whilst the exterior surface of the superheating pipes is about twenty-three square meters, or 240 square feet.

(1.) The furnaces are each divided into two parts by a small partition running along the whole length of the grates. The object of this arrangement is to allow, by an alternate charging of the fuel, the bringing into contact the products of the distillation of coal just charged with the hotter ones arising from a more advanced stage of combustion. Such an arrangement renders the combustion of the gases more complete, for, when a grate is newly charged, there ensues an actual process of distillation which in reality absorbs rather than produces heat; the atmospheric air does not pass through in sufficient quantities, and remains cold, whilst exactly the reverse takes place in a furnace which has been fed some time, and where the coal is in full combustion. Single furnaces must always have, in our opinion, the fault of admitting either too much or too little atmospheric air, and it is useless to expect from an ordinary fireman sufficient intelligence and attention to regulate the stoking in exact accordance with these requirements. Many experiments, all more or less giving like results, have proved that the steam yield of boilers is in proportion to the quantity of the fuel supply, notwithstanding any cooling due to the frequent opening of the fire-doors, and this evidently arises from a more perfect combustion resulting from a fixed supply of air and of the coal. The twin arrangement of the boilers under notice is singularly well adapted to the

application of double fire-grates. The total area of the double furnace is 3.12 square meters, of which one-third is blank, and it is, therfore, nearly equal to $\frac{1}{17}$ of the heating surface. Numerous experiments have been made with the object of determining what is really the best proportion between these two surfaces, and for some time an opinion prevailed in favor of $\frac{1}{45}$ to $\frac{1}{50}$. This opinion was one formed from the result of a series of comparative trials, in which the area of the grates was continuously diminished, the original proportion being $\frac{1}{10}$ of the total heating surface. On these grates the consumption per hour and per square meter of surface was 50 kilogrammes of coal. These quantities were, however, found to be too strictly definite, and they ought to be varied not only according to the quantity of coal burned per hour, but also according to the quality of the fuel, and, when this is inferior, it is, of course, necessary to increase the surface of the grate. The distances of the bars from the boiler is 0.50 meter in front, and about 0.60 meter towards the back; these having been found, as the result of a series of experiments made at Mulhouse, the best distances for semi-bituminous coal, and, it may be added, that they were also found the best for the preservation of the boiler plates. From this point of view, as well as from that of the areas of the grates, these boilers, with the exterior furnaces, exhibit considerable advantages over the Cornish plan of interior furnaces, which latter are considerably in fashion in some parts of Belgium. These exterior furnaces may be easily combined, are easily adapted to circumstances and different wants, from which it may readily be inferred that these advantages are sufficiently great to enable them to hold their own against the interior fire-places, which are, in some respects, certainly superior to them.

(2) *Course of the Flame.*—If it be required that from a given quantity of coal a furnace is to produce the greatest quantity of caloric, it follows that the boilers ought to be so set as to lose the least heat possible; and with this object it seems desirable, whilst giving them a full sufficiency of heating surface, to place this in such a position as to insure the course of the flame being the inverse to that of the circulation within the shell of the boiler. This principle has been most carefully observed in the boilers we are describing. The feed enters one of the lowest tubes at the end opposite the furnace, that is to say, at the point where the products of combustion pass into the stack; from thence the feed-water rises, and, as its heat increases, so does in like manner that of the products of combustion. There is however with reference to the superheating, an exception to this rule. The flame then, after having enveloped the sides of the boiler, properly so-called, and previous to arriving at the lower tubes passes through the superheating chamber, and its movement through this is regulated by several dampers, by the operation of which it is guided either directly to the superheating chamber or to the lower tubes, the result being that the steam is produced at any degree of saturation or superheating that may be desired.

(3) *Superheating.*—After passing over 31.41 square meters of the heating surface, the flame then reaches, and comes in contact with, the cast-iron pipes, through which the steam is passing, and where it is first of all dried, and then superheated. These pipes, made like a coiled worm, are of twenty centimeters exterior and sixteen centimeters interior diameter, the joints being made with iron thimbles having turned expanding collars. This kind of joint has been found to answer exceedingly well, and although the superheating arrangement has been in use several years, not a single leakage has been detected. The heating surface of these pipes was calculated with a view to raising the temperature of the steam to about 240° C. on its leaving the superheater, that is, without having recourse to the regulating valves, which, of course, should be as little exposed as posssible to the action of the fire. This end has been approximately attained, although it was somewhat difficult to arrive thereat by any calculation, *a priori*, seeing that the degree of superheating depends, to a certain extent, on the consumption of steam —which can never be very exactly foreseen—on the heat of the fires, and on the degree of dryness of the saturated steam. It was at first believed that by

regulating the superheating surface in proportion to that of the heating surface of the boiler, an approximately equal degree of superheating would be obtained; for if the fires be hotter, it is surely true that the flame reaches the superheating chamber at a higher temperature; but it is equally true that there is then proportionately an extra quantity of steam to superheat, but in practice this does not hold good, and it was not without difficulty that arrangements were made by which the temperature of the superheated steam could be kept approximately uniform.

APPARATUS AND MEANS FOR MAKING OBSERVATIONS ON THE BOILER.

For the observations on the boiler, a series of apparatus was required, of which we give the following description:

1. *Gauging of the Water.*—A rectangular cistern, containing 2647 liters at a temperature of zero, gauged directly by weight, served to measure the feed-water. Details concerning this tank will be found under the head of "Engine."

2. *Spy-holes in the Firedoors.*—In order to be able easily to make observations on the state of the fire-grate, without opening the doors, a proceeding which always alters the state of the combustion and of the draught, we have constructed in each door small spy-holes with movable covers, which afford means for a ready inspection of the state of combustion of the coal, and its more or less even distribution over the firebars.

3. *Partial Vacuum produced by the Draught.*—It was expedient to measure the draught. With this intention we measured the diminished pressure of air both above and below the firegrate, as well as at the end of the lower flues. These diminutions being slight, small variations in their extent corresponded to great changes in the draught; it was, therefore, necessary to adopt more complicated appliances for making observations than a simple water gauge.

(*a.*) To allow of the pressure below the firegrate to be taken by the stoker *at a distance*, the ashpit was closed in front by a movable damper of thin sheet iron, which in itself constituted an anemometer. A graduated scale showed the angle made by these dampers with the vertical, and allowed of the draught being regulated to the same amount for the same quantity of fuel.

(*b.*) The pressure above the firegrate was registered in a complete manner by means of an ordinary water gauge, modified in two respects. The branch in communication with the boiler had, at the water level, a sectional area 400 times that exposed to the atmosphere, so that any degree of vacuum was registered on this latter branch. Secondly, in this latter branch was a small glass float, which transmitted, by means of a small beam working on a needle point, and in a proportion of ten to one, the differences of level in the water or the difference between the internal and external pressure. By the aid of this appliance, the state of the firegrate could be observed, and its stoking regulated. The readings were easily taken, for each millimeter showed as a centimeter on the scale.

4. *Volume of air admitted to the Firegrate.*—We have seen above that in front of the ashpit were placed sheet-iron dampers, moving easily two and fro under the influence of the draught. They indicated, by the extent they were drawn out of the perpendicular, not only the depression in the gauge, but also the volume of air which passed over the firebars. With this intention, previous to the experiments we are now recording, we had graduated the angles assumed by these dampers by means of a Biram rotary anemometer, which we put in operation at the same time, and under different degrees of draught, so that, after this had been done, the dampers themselves constituted anemometers.

The continual use in front of the boiler of a scientific instrument like the Biram anemometer, is very inconvenient; it is too delicate, and not easily read. We think that by means of our movable and graduated dampers we have practically solved the important question of the volume of air used. The opening of the register affords very poor information to the stoker, for, with the same amonnt of opening, widely different volumes of air may be admitted, which is not the case with our movable dampers.

(4.) *Temperature of the Products of Combustion.*—In the superheating chamber was placed a metallic pyrometer, based on the unequal expansion of differ-

ent metals, which expansions registered themselves on a dial plate by means of a movable needle. This pyrometer was placed at the opening of the superheating chamber, but as, on account of its size, there was no opportunity of obtaining similar observations for comparison, it has been impossible to prove the exactness of its indications, which are, however, believed to be rather low. The temperature of the smoke at the bottom of the stack was first of all examined by placing a copper pipe containing paraffine in the flues, so that it reached the bottom of them, and a thermometer dipping into the paraffine indicated the temperature of the discharge. This arrangement, which, however, is only mentioned that others than ourselves may avoid the false inferences which were drawn from it, presents two defects. First of all, in the long run, the paraffine becomes carbonized, the more readily so because it is impossible to prevent at certain times very high temperature being reached. Besides, in withdrawing the thermometer, not a little dexterity was required in order to read its indications with sufficient quickness. Since then the following arrangement has been adopted :—An iron pipe containing mercury was fixed in the flue, and into this pipe was introduced another containing sand, in which was placed the thermometer. The mercury being a good heat conductor is quickly raised to the temperature of the smoke, and communicates it, *pro rata*, to the sand, which retains it sufficiently long to enable the reading of the thermometer to be easily noted, and this is always a little above the temperature of the sand.

(5.) *Analysis of the Products of Combustion.*—It was deemed desirable to determine the composition of the products of combustion which would permit first of all a judgment being formed on the indications of the anemometer employed to measure the volume of air admitted to the furnaces, and, secondly, to decide what were the losses resulting from imperfect combustion. With this object portions of the escaping gases were drawn off by the aid of a pump at equal distances and heights along the whole of the flues. A portion of these gases was received directly over mercury, and another larger portion over water already saturated with the gas itself. In the analysis, the method by volume, followed by Gerhard and Chancel, of condensing the carbonic acid by potash, the free oxygen by pyrogallic potash, and the carbonic oxide by chloride of copper, was followed. Unfortunately, however, an accident happened during the process of the analysis which prevented its being completed, but it is hoped that this may be accomplished at some future time, and the full benefit of the exhaust obtained.

(6.) *Pressure of Steam.*—The pressure of steam in the boiler was indicated by a mercurial gauge, and the effective pressure in the engine itself by two metallic gauges, controlled by the first-named, of which they at the same time acted as registers. The action of this self-registering gauge is easily understood. The needle rests in a roller moved by clockwork, and surrounded by metallic paper. This paper is divided, longitudinally speaking, into twenty-four parts, representing the hours, and transversely into six, giving the pressure in atmospheres. These diagrams, as regards the pressure, partake of the defect common to all metallic gauges, whose want of exactness frequently leaves much to be desired; but when these are under, as in this case, the control of a mercurial gauge, it is easy to correct false indications by a fresh division of the recording paper on the roller.

(B.)—GENERAL DESCRIPTION OF THE ENGINE.

This is a beam engine, on Woolf's plan, with two cylinders. For the present purpose it will, however, be sufficient to confine ourselves to a description of those peculiarities of construction which are chiefly to be found in the arrangements for the distribution of steam. The admission of the steam into the smaller cylinder is effected by two slide-valves, double-seated, one placed at either end in immediate contact with the cylinder, the object being to avoid waste of space; these are moved by cams regulated by a governor, and it may be added, that this regulating arrangement has been extremely well planned, the speed of the engine altering but little, however different, the effective power produced. The exhaust from the smaller

cylinder is separate from the steam-valve, and regulated by entirely different apparatus; the communication between the top of this cylinder and the bottom of the other, and *vice versa*, being made by a long, movable, square pipe, acting like a slide-valve. This pipe, which, by means of an eccentric motion, places alternately in communication the two opposite ends of the cylinders, is never in connection with the condenser, and besides being always full of steam, is also enveloped in it, the effect of which is to keep it steadily pressed against the smaller cylinder. It hence follows that the steam in passing to the larger cylinder becomes superheated, and that the difference between the pressure in it and the resistance in the smaller one is but trifling, and thus disappears one of the great causes of complaint hitherto put forward against Woolf's system. In the third place, the steam-entrance valves in the large cylinders and those exhausting into the condenser are in like manner separate and distinct; the discharge is made through two slide-valves, governed by an eccentric, and placed at either extremity of the cylinder. These valves, which are simply shells, act, not in an enclosing case and under steam pressure, as is the case ordinarily, but they are open to the atmosphere and merely under atmospheric pressure. This construction reduces to a minimum all waste of space and also friction. To sum up, the following are the merits which are specially claimed for the arrangements:—Instantaneous admission, under the action of the governor, of the steam. Distinct and separate steam and exhaust valves, as well for the smaller as for the larger cylinder. The means of communication (the sliding pipe) between the two cylinders is always full and always enveloped in steam. The exhaust valves of the larger cylinders work simply under the pressure of the atmosphere. Objectionable waste of space is much reduced.

Below will be found the chief dimensions of the engine, on which, however, it is necessary to remark that the ordinary proportion between the areas of the smaller and larger cylinders has been changed from 1 to 4, to 1 to 3.3, with the object of obtaining a longer action in the smaller one, especially so with a view to the superheating. The first intention was to put a jacket to each cylinder and to work with entirely superheated steam. But as a steam-jacket to the smaller cylinder might have had the effect of making the piston cut the face, it was arranged that the jacket of the smaller cylinder should remain filled with air, and that conveniently-placed pipes should convey the steam direct to the smaller cylinder without passing through the jackets. One of the causes for deviating from the original plan was the difficulty found in casting jacketing cylinders, and hence the larger cylinder, and the communication between it and the other, alone have steam jackets.

Chief dimensions of the Machine.—Diameter of smaller cylinder, 0.513 meter; diameters of piston-rod, 0.08 meter; stroke of smaller piston, 1.312 meter; diameter of larger cylinder, 0.795 meter; diameter of piston-rod, 0.096 meter; stroke of larger piston, 1.80 meter; diameter of the air-pump, 0.507 meter; stroke of the air-pump, 0.90 meter; section of opening of slide-valve of smaller cylinder, 0.0079 square meter; section of exhaust of larger cylinder, .0216 meter; diameter of fly-wheel, 6.03 meters; number of teeth, 204; diameter of pinion, 2.54 meters; number of teeth, 86.

Apparatus used for making observations on the Engine.—As for the boiler, so in the present case it is necessary to describe the means adopted for determining the consumption of the engine and the effective work produced.

Gauge for measuring the quantity of Steam consumed.—A tank supplied from the hot well was placed in the foundations of the building. At the commencement and at the end of each trial the water in the boilers was brought to the same level, and the weight of water passing through the tank naturally represented the weight of steam consumed by the engine. This tank, when filled to overflowing, contained exactly 2635½ kilos. of water, at 10° C., or about 2647 kilos. at 0°. It was furnished with two small cisterns, always full of water, one of which contained the feed-pump, and the other a float. The object of this arrangement is readily understood. The area of the reservoir being about two square meters, a slight mistake in taking the height of the water at each empty-

ing might have given rise to a considerable error, whilst this error became almost unnoticeable in the two small reservoirs mentioned. Notice was given of each filling and emptying by a little bell —in electric communication with the two floats—the object of these double floats being to do away with guides or pulleys, whose varying friction is apt to induce error. Thus there were guaranteed a certainty of measurement and instantaneous electric signals, and these were further arranged so as to give warning whenever the feed was three centimeters either above or below the level.

Determination of Temperatures.—The temperature of the steam was observed at six different points; that is to say, in the seating of the boilers before the superheating; and, after this, in the entrance to the engine-house; afterwards, close to the smaller cylinder; then, as it issued from the jacket of the larger cylinder; and, finally, in its discharge from the latter. The temperature of the water used for condensation, and of that discharged by the air-pump, were also measured. The taking of these temperatures presented more than one difficulty. In the first place the thermometers used did not agree, and in some instances the differences between them amount, for superheated steam, to 5° C. It was found possible, by experiments referring to boiling water and saturated steam of a known pressure, to correct the lower temperatures; but in the higher ones, those recorded can only be considered as approximate. Then there were obstacles to the observation of these temperatures entirely independent of the instruments, as from the fact of some of these getting broken it became necessary to move the others from place to place, and their indications were thus affected, it being impossible sometimes to wait sufficiently long to permit either registration by them of the changed temperatures or the correct reading thereof. This is much to be lamented, but is mentioned to prevent any too absolute conclusions being drawn from the results recorded.

Number of Strokes.—A counter placed in front of the engine and moved by an eccentric, gave the number of strokes, which were duly recorded every quarter of an hour.

Indicators.—The work done by the steam in the cylinders was registered by four Richards' indicators placed at either end. Attention was given to the springs of these by having them tested by a mercury gauge. Motion was imparted by the parallel motion, so arranged that the attachments were vertical and proportionate to those of the pistons. During the first trial, which lasted thirty-six hours consecutively, diagrams were simultaneously taken every quarter of an hour at either end of the smaller cylinder; and four diagrams, also simultaneous, of the two cylinders every two hours. The proportion, sufficiently regular between the work of larger and smaller cylinders for every period of two hours, was added to the diagrams obtained every quarter of an hour from the smaller one, and thus the total effective work was defined. The three following trials lasted for twelve hours each, and to decide as to the effective work four diagrams were simultaneously taken every half-hour. The work done when the engine was rnnning light was also calculated, together with the friction of the whole, including that of the pinion and its axle.

Condensation of Water.—The condensed steam from the pipes and steam jackets was delivered into vessels of a known capacity, which were alternately filled and emptied. Practically speaking, this condensed water ought to be utilized by returning it to the boilers, but this was not done, it being thought more interesting to determine its exact quantity; it should, however, be understood that the results obtained from the engine ought, strictly speaking, to be compensated for any loss thus sustained.

Condensing Water.—It has been said that the temperature of this water was taken every quarter of an hour, but it was also desirable to measure its weight, to which end the air-pump was arranged so as to throw, when so wished, all the water into the reservoir, gauged at 2747 kilos., used for feeding the boilers, as has been mentioned above; this was easily done by means of a communicating pipe, and thus every time it became necessary to fill this gauged reservoir for feeding the boilers, the capacity of the air-pump could be registered with every desirable exactness, by noting the number of

seconds employed in refilling, and, as a further guide, the number of strokes made by the piston of the engine.

We may now examine the results of the experiments made, in which M. A. Devigne, Engineer, M. de Veer, M. Nicodème, fils, Engineer, M. Louis, and M. Lemaire, actively participated. Each scrupulously performed the task allotted, notwithstanding the labor involved in such experiments. Success has crowned their efforts, for no accident has occurred of sufficient importance to cast any doubt upon the accuracy of the results obtained. These results are given in the following table, several points in which we shall examine further on.

(*See Table on following page.*)

N. B.—In a previous trial made between the 13th and 15th of March, and comprising 64 hours, 4 minutes of working, during which the engine had made 96,814 revolutions (say 25.12 per minute), and had given off a power manifestly equal to that of the subsequent official trials, a consumption of 86.76 kilogrammes of steam per hour had been shown—say 7.88 kilogrammes per effective horse-power. The consumption of coal during the last 24 hours of this trial had been 121.2 kilogrammes per hour of the same coal (16 per cent. of ashes)—say 1.10 per effective horse-power per hour approximately, or 1.03 kil. per effective horse-power, deducting six per cent. of ash. Through the want of assistants during this trial, we were unable to take all the observations which it admitted of. This certainly does not impeach the fact that length and multiplicity of trials and the agreement of their results are a great guarantee of correctness.

The results of the experiments contained in the table give rise to a great number of questions. Time fails us to analyze them so much in detail as they deserve, we must therefore confine ourselves at the present time to the following points:

EXAMINATION OF THE RESULTS.

Coal.—The fuel used was the poor coal of the Charleroi basin, which, moreover, had been lying in the open air, exposed to all the inclemencies of the season, for about six weeks prior to the date of the experiments; and under these conditions the yield of steam was naturally less than it otherwise would have been. The reduction of ten per cent. for incombustible matter, which, it will be observed, has been made throughout the table, may be justified in this way—that, first of all, there was an understanding with the contractor that the coal contained ten per cent. of ash; and secondly, that the experiments were thus placed on a common footing with those at Mulhouse, where a similar proportion was allowed. The variable quality of the cinders, as proved during the different trials, may be accounted for by the following out of different systems of stoking; the fact being that in the later experiments the furnace fires were more frequently stirred, the result being a darker color in the cinder.

From every charge of 60 kilogs. of coal a sample was taken, and from these samples, after they had been mixed together and pounded, a specimen was selected, which, on being calcined, was found to contain an average of 8.6 per cent. of valueless matters. The results of these tests showed that there ought to have been in the cinders from the grates at the different trials 12.25 per cent., 9.20 per cent., 7.45 per cent., and 9.4 per cent. of combustible matter.

The examinations of these cinders, of which average samples were in like manner taken, does not, however, quite confirm this induction. Thus, the calcining of the cinders of the first trial gave 373.2 kilogs. of valueless matter, whilst the proportion of 8.6 per cent. in the coal would represent 404.2 kilogs., or a total difference of 31 kilogs. of valueless matter, and this difference of 31 kilogs. represents on the 4700 kilogs. of coal burned an excess amounting to 0.7 per cent. The question then arises whether there be an error either in calculating the effect of the calcining, or in the data of the experiments; but at the same time it may be readily admitted that it is very possible a portion of the cinders had been carried off into the flues of the boilers, in which case there is nothing extraordinary in a larger proportion of useless matter being found in calcining the coal than in calcining the cinders.

This poor coal is extremely apt to work down through the grate bars, but careful stoking had the effect of realizing

(C.)—Result of the Experiments.

	With superheating.		Without superheating	
Date of the trials, 1873	Mar. 18.	Mar. 24.	Mar. 25.	Mar. 26.
Duration of trial	35h. 30m.	12h. 10m.	12h. 10m.	11h. 32m.
Total consumption of coal	4700k.	1500k.	1700k.	1600k.
Cinders, clinker, &c., drawn from the grate for every 100k. of coal consumed	20.85	17.80	16.05	17
Consumption of coal per hour, deducting ten per cent. of ash,	118.	113.64	131.22	129
Consumption of coal per square meter of grate-bar	37.82	36.42	42.05	41.34
Ditto per square meter of heating surface	10.26	0.988	1.14	1.12
Mean pressure of steam in the boiler as measured by mercurial gauge	4.35 atm.	4.38 atm.	4.19 atm.	4.17 atm.
Temperature of steam in the boiler prior to superheating, cent.	154° 7	154° 9	153° 6	153° 4
Ditto after superheating	247°	232° 8	153° 6	153° 4
Temperature of the external atmosphere at mid-day	10°	15°	15°	15°
Temperature of products of combustion at the entrance of the superheating chamber	350°	350°	333°	339°
Ditto, Ditto, prior to its entrance into the chimney	176°	154°	156°	162°
Quantity of water evaporated during the trial, estimated in liters	31,626	11,214	12,966	12,001
Temperature of the feed-water	28° 8	28°	28° 4	28°
Quantity of water evaporated during the trials, in kilos	31.368	11,078	12,806	11,855
Ditto, ditto, ditto, per hour	883.6	910.5	1052.4	1027.8
Quantity of water evaporated per kilo. of coal consumed, this latter being supposed to give ten per cent. of ash	7k. 45	8k. 01	8k. 01	7k. 97
Average pressure in the engine	4.20 atm.	4.18 atm.	4.10 atm.	4.03 atm.
Pressure in the condenser in centimeters	68	69.1	69.7	69.3
Temperature of the steam in the engine	217	202.1	152.9	152.3
Temperature of the steam at the lesser cylinder before passing through steam jacket	193	188.7	152.9	152.3
Ditto, after passing through steam jacket	169	—	152.4	—
Temperature of the steam in the exhaust pipe from the larger cylinder	49.60	48.74	48.86	49.60
Temperature of the condensed water of the steam jacket	95°	95°	95°	95°
Weight of the condensed water	2390k.	473	1467	4.35
Ditto, ditto, per hourly discharge	67k. 32	38.88	120.57	37.68
Temperature of the injection water of condenser	9¾°	9¾°	9¾°	9¾°
Temperature of the water at the discharge of air-pump	31° 12	27° 76	29° 9	29° 5
Quantity of water discharged by the air-pump per minute	350.470k.	378.542k.	406.08k.	405.00k.
Caloric units, or quantity of heat added per minute to the injection water by the discharge of the steam	7489.44	6817.54	8182.61	7998.75
Number of strokes of the engine per minute	25.33	24.99	25.00	24.68
Effective result of steam in smaller cylinder estimated in horse-power	73.654	77.630	72.110	76.600
Effective result of steam in larger cylinder estimated in horse-power	46.518	42 850	50.520	43.890
Total work done in the cylinders	120.172	120.480	122.630	120.490
Friction of the engine as estimated in horse-power	11.04	11.04	11.04	11.04
Effective work done by engine	109.132	109.400	111.590	109.450
Consumption of fuel, allowing for ten per cent. of cinders, per horse-power per hour	0.981	0.943	1.07	1.07
Consumption of coal containing, say, ten per cent. of ashes per effective horse-power per hour	1.080	1.038	1.176	1.176
Consumption of steam per horse-power per hour	7.353	7.560	8.580	8.530
Consumption of steam per hour and per effective horse-power	8.096	8.320	9.430	9.390

an economy of say, 5 per cent. in the cinders as compared with ordinary firing; for this economy it was found advisable to have the grate bars placed very close together, to wet the coal a good deal, and to give it plenty of draught, which dispenses with the necessity for frequent stirring of the fires and the frequent cleaning of the grates.

Draught.—The draught, or volume of air admitted to the furnaces, was maintained, apart from the first twelve hours of the first trial, at a regular quantity during the whole course of the experiments. During the said first twelve hours of the first trial it was about 9 cubic meters of air per 1 kilog. of coal consumed, which was certainly insufficient, whilst for the remainder of the experiments it reached nearly 10.28 cubic meters, or about 13.5 cubic yards, per kilog. of coal burned. How far is this sufficient? The composition of the coal consumed may, we think, be taken as approximately the following:

Carbon	82.00
Hydrogen	4.40
Cinders	8.60
Oxygen, nitrogen, &c.	5.00
	100.00

And thence, taking into consideration the carbon and the hydrogen only, there would be necessary 906 liters of air at zero, or about 955 liters (210 gallons) at 15 deg. C. for combustion. There would thus appear to have been in general during the trials an excess of air equal to about 7.1 per cent. In one of the analyses, the correctness of which, however, cannot be definitely relied on, an excess of three per cent. of oxygen, or about fifteen per cent. of air, was found in the products of combustion, or nearly about double that which has just been given above. This, however, may be explained, and the analysis gains in value thereby; for in reality there were lost or left in the cinders from seven per cent. to nine per cent. of the combustible matter, which evidently did not absorb any air; and beyond this is the fact, that however great may be the draught absolutely, perfect combustion is not attainable, as has been very amply shown by M. Schreurer-Kestner, in his very beautiful researches on the combustion of coal. According to these researches, and under the conditions with which these experiments were carried out, from five per cent. to six per cent. of carbon would escape in the form of carbonic oxide, and nearly twenty per cent. of the hydrogen contained in the fuel would also escape unburned.

Cost of the Draught.—If from this information, combined with the results of the experiments before us, we calculate the cost of the draught, we find ourselves in face of two losses, one of which increases whilst the other diminishes in proportion to the draught; the first of these arising from the heat escaping up the chimney, and the second from imperfect combustion. Let us now see what is the actual value of these losses. 1028 liters of air at 15 deg., weighing, with the matters carried with them (0.83 kilogs.) a total of 13.88 kilogs.—about 30.75 lbs.—have been admitted through the furnaces. The temperature of the gases being 162 degs. C.—355 degs. Fahr.—at their exit, and 15 degs. C.—59 Fahr.—at their entrance, there were lost $147 \times 13.88 \times 0.23 = 468.18$ units of heat per kilog. of coal. This is admitting, for the facility of calculation, an average specific heat equal to 0.23 for the gas at its exit from the chimney; these calculations will scarcely allow of much greater exactness; and a loss of a fifth part—say 93 units of heat—thus arises from an excess of air.

There was given off in the state of carbonic oxide about six per cent. of the carbon contained in the coal, say 0.0492, which equals a loss of $0.0492 (8080 - 2403) = 229$ heat units; 8080 and 2403 being the heat units respectively developed by the transformation of the carbon into carbonic acid and carbonic oxide. On the other hand, the disengagement of 0.0088 kilogs. of hydrogen occasioned a loss of $0.0088 \times 34{,}600 = 184$ heat units, the total loss arising from an imperfect combustion being thus 413 heat units. If, however, the quantity of air admitted through the furnaces had been increased twenty-five per cent., the losses arising from imperfect combustion would have been diminished one-half, as M. Schreurer-Kestner has demonstrated, and there would thence have been a gain of about 200 heat units, but a loss from the gas passing off through the chimney of, say, 117 heat units; it thus

appears that there would have been some gain from an increased supply of air.

Duty of the Boilers.—In order to present our balance-sheet of the duty of the boiler the result of the second experiment is selected because it was the best average; the first having been made under the disadvantages of varying draught, whilst the two last suffered from an uncertainty as to the quantity of water carried in, mechanically, by the saturated steam.

The approximate heating power of the coal burned ought to have been, as calculated from its component parts, nearly 8147 heat units. On the other hand, the products of combustion of 1 kilog. of this coal may be thus estimated:—(1.) $7.32\ (606.5+0.305\times153.6+0.4805\times79.2)=4782+278=5060$ heat units; from which however, must be deducted for heat units contained in the feed-water, say $28\times7.32=205$ heat units.

	Heat units.	Per cent.
There remain, therefore, as represented by steam.....	4855 or	59.59
(2.) The combustible matter lost in the cinders represents 0.092 ×8080=.....	743 or	9.10
(3.) The gases escaping through the chimney have carried with them (154—15) 13.88+0.23=.	444 or	5.43
(4.) Imperfect combustion represents.....	413 or	5.07
(5.) The evaporation of 1¼ per cent. of water in the fuel represents.....	10 or	0.12
(6.) The radiation, or losses through the brickwork, losses arising from the cleaning of the grates, and other causes which have not been estimated represent the difference=.	1682 or	20.52
Total.....	8147 or	99.83

It is not claimed that in the totals of these losses the exact proportion of each of them is given; for that it would have been necessary that the analysis had been more positively defined by an experiment with the calorimeter on the calorific value of the coal burned. The impression, however, is entertained that the figures given deviate but little from the actual truth.

What will strike people most is the high figure, 20.52 per cent., which stands last in the table of losses, and which M. Schreurer-Kestner attributes entirely to radiation. It is thought, however, that there ought to be added thereto as causes—(1.) The fusion of the cinders, the cooling and losses arising from cleaning the grates. (2.) The entrance of air at the dampers and round the lower tubes, entrances which the anemometer could not measure, but which it was endeavored to reduce to a minimum; and then, (3), probably another cause, which M. Paul Charpentier has investigated in the *Revue Universelle*, namely, the faculty possessed by the products of combustion of freely expanding. "If," says he, "burned gases are allowed to expand freely, and their initial pressure to diminish, there arises an absorption, in the latent state, of a quantity of heat, which has not as yet been exactly determined, but which is, nevertheless, of importance; if, on the contrary, this expansion be restrained, the heat will take an appreciable form, and may be usefully applied." And as a corollary to this, the same writer has proposed a method of combustion which merits the attention of manufacturers, and which he denominates, "A method of perfect combustion by fixed quantities." Our opinion, however, is that the loss arising from the free expansion of the products of combustion has been much exaggerated.

On this point, reference may be made to the mechanical theory of heat—a theory utterly rejected, it is true, by M. Martin, but the results of which have been so often approximately verified that it seems fair to make use of them here.

The air entered the furnace at a temperature of say fifteen degrees, and left it, in the experiment we have been analysing, at a temperature of 154°. Its volume was thus augmented by about fifty per cent., this augmentation taking place by overcoming the pressure of the atmosphere, and in accomplishing, therefore, by cubic meter of air admitted, the work of 1.03+50,000 kilogrammeters, corresponding to 121 heat units; or for every kilo. of coal burned there were admitted 1028 liters of air—hence there was lost per kilo. of coal $1.028\times121=123$ heat units, being only about one and a half per cent. This quantity is much smaller than the author just quoted supposes. He gives also, as the ordinary result of heating, a very different yield

from what has been found above—his table of losses being as follows:

	Per cent.
1. Loss due to excess of air	16
2. Loss due to the chimney	18
3. Loss due to imperfect combustion	20
4. Loss due to formation of cinders	15
5. Loss due to evaporation of 48 kilos. of water	3.6
6. Loss due to radiation	see details.
Total	72.6

These figures have nothing in common with what takes place underneath boilers hung under moderately good conditions; they, in fact, assume impossible temperatures at the bottom of the stack, and an imperfection of combustion beyond all ordinary limits. The author himself feels that his loss is over-estimated, and is not at all in accordance with the ordinary duty done by steam boilers; but he flings himself then on the 40 per cent. of water mechanically, in many cases, carried in with the steam. That this water is often a cause of uncertainty must be acknowledged; but with superheating this uncertainty disappears.

Prior to the experiments now reported a dozen trials were made with coal from different collieries, and with ordinary dry steam, that is, superheated about 2°. The average of these trials, which lasted about 422 hours in the aggregate, gives a duty of 8.14 kilos. of steam per 1 kilo. of coal. We believe this duty to be capable of improvement even with ordinary boilers; but it is reproduced here, as it is considered a very strong confirmation of the preceding observations and calculations.

It is no part of this report to enter on a discussion of the comparative merits of different systems of boilers, its object being simply to render an exact account of the duty done by those experimented upon. We will, however, add, that in our opinion if tubular boilers give a better duty, the ordinary cylindrical ones have the not unimportant merits of simplicity and facility for cleaning, which at large works ought to be appreciated, the more especially when the water happens to be laden with matter inclined to cause incrustation.

Temperature of the Steam.—The loss of temperature between the boiler and the steam cylinder has, notwithstanding that the pipes were enveloped in a non-conducting coating of paper pulp the greater part of their length, and were placed in some places underneath the earth, been very great with the superheated steam. This loss was 54° during the first trial, and 44° during the second. On this subject there is room for some observations; the difference of 10° in the loss arising from the fact that it was considerably colder, especially during the night, on the occasion of the first trial. During the day the respective temperatures of the external air were 10° and 15° C., and the loss of heat by radiation being proportional thereto is hence greater for superheated than for saturated steam. It was wished to account for the difference in these losses by registering, on one hand, the fall in temperature for the superheated steam, and, on the other, the condensed water for the saturated steam. Knowing the specific heat of the superheated steam, and the number of heat units contained in the saturated steam, the thing was simple enough. A result was, however, found exactly the reverse of what we had anticipated—in fact, the condensation of the saturated steam showed a loss of heat greater than the fall of temperature in the superheated steam. The explanation of this apparently irrational matter rests in the mechanical carrying forward of water in spite of all the precautions taken to prevent it. Since the trials which have been described, during the summer months a series of observations have been made on the loss of temperature, which has been found reduced to 32° C. in place of the 54° and 44° previously determined, and the system of pipes being about 32 meters in length prior to its reaching the engine, thus gives a loss of about 1° per running meter, or about 2½ per cent. of the heat contained in the steam. This loss, still too great, but which might possibly be reduced by better covering to the piping, is worthy the attention of persons contemplating the use of superheated steam, especially on the point of such arrangements as would bring the boilers and engines closer together. Placing on one side all theoretical calculations, which for the moment it may be desirable to avoid, the fact of the great facility with

which superheated steam loses temperature may be brought forward as a proof of the small quantity of heat required for its production in the abstract sense of the term. This loss is evidently a phenomenon identical with, though inverse to, that of the heating. Any matter which is easily cooled is in like manner easily warmed. The changeableness of the circumstances and of the primary causes which govern the yield of steam from a boiler have the effect that, in spite of all precautions, no two yields are alike; and hence, secondly, make it impossible to determine how far that yield is affected by superheating. Prior to the experiments recorded, a difference of 0.85 kilo. of steam per 1 kilo. of coal burned in some trials made by Messrs. Gilain, testify to differences still more considerable found at their works, which can only be explained by the mechanical carrying forward of the water.

ON THE FLOW OF FLUIDS THROUGH NOZZLES.*

By ROBERT D. NAPIER.

From "Engineering."

In the preface to the second volume of "Weisback's Mechanics," there is a remark to the effect that mathematicians are sometimes so charmed with the beauty of their analytical processes as to forget to inquire whether their premises are correct. Several examples of this have come within my own observation, and I believe that to similar causes is to be attributed a good deal of misconception with regard to the action of water flowing through an orifice in a thin plate.

Before the present generation it used to be generally considered that the power or force which was theoretically available for producing the flow, was equal to the area of the orifice multiplied by the pressure due to the head; that is, equal to the weight of a column of water of which the cross-section is equal in area to that of the orifice and the length equal to the height of the water above the orifice.

In the former times to which I refer, it was argued, as it has been since, that the theoretical velocity through the orifice was that which a heavy body would acquire in falling freely through a distance equal to the head, but that the obstruction caused by the convergence of the moving particles towards the orifice, and by friction, made the actual discharge only about five-eighths of the theoretical quantity.

In reasoning thus a serious oversight was made, which was nothing less than assigning to the theoretical force just double the duty it was possible it could perform; for it can be easily shown, and I shall presently do so, that if the velocity through the orifice were that which a heavy body would acquire in falling through a distance equal to the head, the momentum of the water that would be discharged in a given time would be double that which the assumed theoretical force could generate in the same time.

On the other hand, if the water were not to flow at nearly the velocity due to the head, there would be a loss of work which it would be difficult if not impossible to account for.

The question then arises, how can the amount of work that is potential in the water before it flows through the orifice, be transmitted to the same amount after it is discharged, without infringing the law that the momentum of a moving mass is proportional to the force and time required to generate its velocity?

Many persons have got over this difficulty by an easy, but rather cavalier, process. They have ignored the name and even the idea of momentum, and determined the theoretical flow entirely, by considering the equality that should theoretically exist between the potential work in the water, before flowing through the orifice, and the accomplished work after that.

These two quantities might be per-

* Paper read before the Philosophical Society of Glasgow.

fectly equal though the *vena contracta* were a tenth of the size it is in reality, so that this method of solving the problem is simply escaping from between the horns of a dilemna by ignoring the existence of one of them.

But the commonest method of getting over the difficulty is by doubling the theoretical discharging force, and then accounting by an ingenious fiction for the fact that the work accomplished does not indicate the existence of the supposed double force.

When it came to be understood that if water flowed through an orifice at any given velocity, the constant force that would be necessary to produce that stream would be twice as much as had been previously supposed requisite, then the obvious conclusion should have been drawn that as there was only power to do half the work expected, therefore theoretically only half the work could be done. In place of which the opposite and remarkable theory was started, that as the proposed work could not be done without double the available power, therefore that force must somehow exist or ought theoretically to exist. It was known that the work actually accomplished is only about five-eighths of what the imaginary power should do, and then it was argued that this must be caused by the obstruction to the flow caused by the stream converging towards the orifice.

An esteemed mathematical friend explained his idea of the matter to me some years ago by saying that water flowing through an orifice in a thin plate was very much like an enlightened British public crushing to get through a door-way, and thus getting through at a slower rate than if they arranged, as in some countries, to approach the passage in more nearly parallel lines.

This ingenious if not very logical view of the case was adopted in spite of the fact that the *vena contracta* was proclaiming in visible language how nature had arranged to overcome (not to ignore, as many mathematicians had done) the difficulty of reconciling the laws of momentum with those of work as measured by force into distance.

The fact is, it is about as difficult to conceive the idea of water flowing through an orifice in a thin plate without a *vena contracta* as to imagine its getting to the orifice without converging stream lines; and it is about as logical to say that the contraction of the vein is the cause of the converging stream lines, as to say the reverse. They are each necessary to any intelligent conception of how the action of water flowing through an orifice could take place.

Some persons may think that discharging water through a projecting tube is a case in which there is no *vena contracta;* but it might just as well be said that when the converging stream lines are not visible they do not exist; for the *vena contracta* takes place in the tube as certainly as it does in the air, though perhaps it is slightly larger.

I do not know who first gave expression to the idea, but it has come to be an accepted proposition, that the theoretical discharging force is equal to the area of the orifice multiplied by twice the head.

Now supposing that this statement were substantially correct, there is an impropriety in speaking about twice the head acting on the area of the orifice in place of the head acting on twice the area of the orifice which, to say the least of it, is extremely unfortunate, for there is no doubt it has done incalculable harm by producing confused conceptions on this subject, not only in the minds of beginners but of mathematicians as well.

No double head either exists or had any right to be supposed possible, but the actual head might be conceived to act on double the area of the orifice; that is to say, that the pressure on the surface round the orifice might be conceived to be less than the pressure due to the head, by an amount which would be equivalent to that pressure acting on an area equal to the size of the orifice.

We know by experiment that there is a reduction of pressure equal to about one-fourth of this, and we should have been justified in anticipating a reduction to some extent; but it seems to me, that theory has no more right to take this into account on the one hand than it has to take friction into account on the other, as nothing but experiment I suppose could give us the least idea of the value of either factor.

My contention is as follows: 1. That the theoretical velocity is the velocity

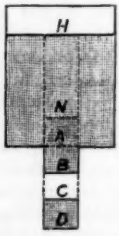
due to the head, since otherwise there would be a disappearance of work which was potential in the water; 2. That the theoretical discharging force is equal to the area of the orifice multiplied by the pressure due to the head; 3. That this force could only produce the momentum that would be generated by a stream whose sectional area was half the size of the orifice, and the velocity of which was that due to the head; and, lastly, that it follows that the theoretical *vena contracta* is half the size of the orifice.

By Mr. Froude's analysis of the *vena contracta*, brought before us by Sir William Thomson, he arrives at the same conclusion and from similar premises, and his experiment was a convincing argument in favor of the soundness of his views, but his demonstration that half the size of the orifice is the true theoretical *vena contracta*, is not the first that has been given.

In a pamphlet published by myself in 1866 I argued at considerable length, and I think I proved, that in place of the convergence of the current towards the orifice being the cause of the *vena contracta*, it was more correct to say that it accounted for the fact that the vein only contracted to about five-eighths instead of to half the size of the orifice, which was the true theoretical *vena contracta*.

By referring now to Fig. 1 it will be

FIG. 1.



easy to explain the original method of deducing the theoretical discharge, the mistake that was made, and also my method of determining the theoretical *vena contracta*. The diagram represents a cistern with an orifice in the bottom of it, and filled with water to the height A H.

Now if the orifice were plugged up, the pressure on the plug would be equal to the area of the orifice multiplied by the pressure due to the head A H, or equal to the weight of the column of water A H; and this weight or force was considered to be the theoretical discharging force, which I also say it is. If the plug is removed, and the column A H is allowed to descend by its own weight, then by the the time the top part of the column is level with the orifice it will have acquired the velocity due to the height or head A H.

Again, if the same force were to act on a portion A N, which we will suppose is $\frac{1}{n}$th of the column A H, then by the time that the top N arrives at the orifice it will have acquired the velocity due to head A H as in the first case, for we should have n times the proportional force acting for $\frac{1}{n}$th of the distance, which would generate the same velocity as the total weight acting through the distance A H. From this it was argued that if n were supposed to be indefinitely large, there would result a constant stream through the orifice at the velocity due to the head. In this reasoning it was overlooked that if the whole force were employed in giving velocity to the portion N A till it got into the position A B, then the succeeding portion taking the position N A would be stationary, and the average velocity of each portion during its passage through the orifice would only be half the velocity due to the height A H.

If we now suppose the velocity of each part to remain constant after it has passed through the orifice, and that velocity is twice the average velocity during its propulsion through the orifice, then by the time the second part N A had got into the position A B, the first part would be in the position C D at a distance B C equal C D from A B.

Then we should ultimately have the space below the orifice filled with alternate equal spaces of air and water; but it would be absurd to expect an intermittent action, and the only legitimate conclusion that we should have a right to draw if we had not seen the experiment, would have been that the stream should reduce to half the size of the orifice in a theoretical point of view.

On the other hand, we might most reasonably have anticipated that there would be a reduction of pressure round the orifice which would by so much increase the discharging force, and thus make the section of the stream at the narrowest part somewhat more than half the size of the orifice; but on no principle that I can conceive have we any right to assume that this decreased pressure should be equal in amount to the whole weight of the column A H, and thereby double the true theoretical force.

Sir William Thomson told us that the calculation of the *vena contracta* had completely baffled mathematicians, and I am not surprised to learn that it has done so, for they have all along been trying to explain *why it is so small in place of why it is so large.* I cannot say whether or not it is within the scope of pure mathematics to calculate the actual *vena contracta* on the supposition of the fluid being theoretically perfect, but it does not require abstruse mathematics to see when a question like this is turned wrong end foremost, and I can readily imagine that such a process would be somewhat baffling to the most profound thinkers.

Had Sir William Thomson informed us that the adoption of the premises on which Mr. Froude's method of determining the theoretical *vena contracta* is based, would require the inversion of the reasoning hitherto used on the subject, and that even the adoption of his deduction without reference to how it was obtained would have the same effect, there would have been little occasion for this paper.

But as far as I could judge, it did not appear to have occurred to him that such a result must follow, for I certainly understood him in his concluding remarks to indicate that the converging stream lines towards the orifice were after all the cause of the contraction.

Now if the theoretical *vena contracta* is half the size of the orifice, then what becomes of the doctrine that is all but universally held, that theoretically the velocity through the orifice should be that which a heavy body would acquire in falling a distance equal to the head, when of course there would be no *vena contracta* at all? And if the experimental *vena contracta* is about a fourth part larger than the theoretical size, what becomes of the explanation usually given that the contraction is caused by the obstructive nature of the converging currents? Both propositions cannot be true.

As already suggested, a great deal of the darkness that has enveloped this subject has arisen from ignoring the laws and even the very idea of momentum, and Mr. Froude has done good service in restoring that neglected word and idea to its ancient and rightful position in the consideration of this subject.

The argument on this question in my pamphlet was conducted in words, and was not so concise as it should have been, and many mathematicians have a difficulty in following reasoning which is not expressed in algebraical form, yet I am somewhat surprised that what was published and in the hands of, to my own knowledge, several leading mathematicians nearly ten years ago, and was then thought to be nothing new, should be brought forward now as a novel and beautiful discovery, and that this should arise entirely through the arguments then and now being attired in a different dress.

I am more particularly surprised that Mr. Froude should have been so long in coming to the conclusion he has lately done, because in conversation with him about nine years ago, when I gave him one of my pamphlets, I found that our views about the flow, not only of liquids but of gases, coincided almost exactly. Among other things we both held what I think I may safely say was then the very advanced opinion, that when discharging through a compound nozzle, consisting of a suitable converging and diverging part, that it was theoretically possible with an indefinitely small head to produce a perfect vacuum in the throat; at least that was my view of the matter, and he certainly held views that directly led to that conclusion, if he had not then quite adopted it.

The experiments of Mr. Moreton and of Mr. Brownlee, by which they obtained a vacuum in the throat of from five to six times the primary head, have gone far to prove that this view was correct; but it seems odd that, holding this opinion at that time, Mr. Froude did not sooner reduce into mathematical lan-

guage the demonstration that I had given that half the size of the orifice was the true theoretical *vena contracta.*

I now propose to demonstrate that the *vena contracta* is caused directly by the increasing velocity between the orifice and the *vena contracta;* that this increasing velocity arises from decreasing pressure for the same distance, and, therefore, that the *vena contracta* is not caused by the convergence of the stream towards the orifice on the other side of it.

This last statement must be understood in the sense that the converging stream lines do not act as an impediment, and reduce the actual discharge below the theoretical quantity. In one sense the convergence of the stream towards the orifice is the cause of the *vena contracta,* for without the converging stream lines the pressure in the contracting vein could not be kept up; but on the other hand neither could the flow take place, when the whole question would collapse.

My argument consists of only a few steps, and each of them seems to me to be beyond dispute.

1. We know experimentally that the vein contracts for some distance outside of the orifice, and that, therefore, the velocity increases for the same distance.

2. We know that it is a law of nature that nothing but greater pressure on one side of a particle than on the other can alter its velocity.

3. It follows that there must be internal pressure in the contracting vein, which gradually diminishes throughout the contracting part.

Having arrived at this certain conclusion we can reverse the reasoning as follows:

1. We are certain that there is in all the contracting part of the stream an internal and decreasing pressure from the orifice to the *vena contracta.*

2. We know that the decreasing pressure must produce increasing velocity, which must produce gradual diminution of the section of the stream.

3. We know that nothing but decreasing pressure can produce the increase in the velocity which is essential for the contraction of the vein.

4. It follows that the convergence of the stream lines towards the orifice cannot be the cause of the *vena contracta* (Q. E. D).

Diagram 2 represents the actual shape that water would take when flowing through the orifice from a head A H.

FIG. 2.

Now no one will dispute the statement that from the *vena contracta* B to the position C, the decrease in the cross section of the stream is caused entirely by the increasing velocity; surely then we have a right to suppose, unless it can be proved to the contrary, that the same cause produces the diminution in the remaining part A B of the stream.

In this reasoning I have left out of account a small effect that would be produced in the way of contracting the vein which would result from the centre part of the stream moving at a greater velocity than the outer parts of it, but the effect of this must be very small in proportion to the total effect produced.

Independently of all that has been said here on the subject, there is experimental proof that the rushing of the liquid particles towards the orifice does not appreciably, if at all, cause any obstruction to the flow.

The experiments of Venturi showed that water flows through the *vena contracta* at about 97½ per cent. of the velocity due to the head, which shows that an orifice in a thin plate is within a little of being a perfect arrangement for discharging water without loss, in place of causing about 35 per cent. of loss as is generally supposed, for if there were anything of the nature of obstruction to the flow it would most certainly be exhibited in the loss of velocity of efflux.

If nearly the whole potential work in a mass of water at a height h is exhibited by the velocity which an equal mass of water acquires in being discharged from a head h, it follows that

there has been very little obstruction to the flow. The fact is, that with an orifice in a thin plate nature is allowed free play, takes her own course, and when we come to look at it, a very *natural* and almost the only conceivable course; she produces part of the velocity on one side of the orifice and part of it on the other side, but to call that arrangement obstruction, and to say that nature would have shown herself more of a mathematician if she had arranged to do all the work on one side of the orifice, seems to me to be perfectly unwarrantable; and I heartily thank Mr. Froude for demonstrating, in mathematical language, the fallacy of the reasoning by which these conclusions were arrived at. The inversion of reasoning that has taken place with regard to the subject of these remarks is something quite unique and complete.

First of all a theory is adopted, which makes out that a certain amount of work should be done; then a double-headed phantom is invented to do the proposed work; then because the work is in reality not done, it is argued that that arises mainly from the fact that the phantom is in such a hurry to do its work that it trips itself up and blocks up the orifice it is trying to get through. Finally, the convergence of the stream lines towards the orifice, which is absolutely necessary for the very existence of even a shadow of the phantom, is accused of creating so much obstruction on that side of the orifice as to cause a large amount of work to be done on the other side of it.

In reality about sixty per cent. of the work of producing velocity is done outside of the orifice, and this work is tried to be accounted for by obstructions on the inner side of it. To me this seems one of the most astonishing conclusions to arrive at that could possibly be conceived.

Appendix.

When it is stated, as is generally done, that the experimental discharge through an orifice in a thin plate is about five-eighths of the theoretical quantity, this must mean, if it means anything, that about three-eighths of the theoretical power is lost by *obstructions* which theory does not take into account. A similar remark applies to the hitherto accepted dictum, that when the discharge is through a tube projecting inwards the actual discharge is about half of the theoretical quantity, which must mean that in this about half the theoretical power is lost.

Sir William Thomson brought before us four weeks ago, and accepted as correct, the views of Mr. Froude about the latter case. According to these views regarding the case of an introverted tube, the theoretical discharging force has been hitherto assumed to be double that which a true theory would give, and by making this alteration it is found that the theoretical *vena contracta* and discharge nearly agree with the experimental ones.

If this is correct then there is no loss whatever from the convergence of the stream in this case, in place of, as is generally considered, there being about half the power lost, and *a fortiori*, neither is there any loss in the case of an orifice in a thin plate where it was supposed that three-eighths of the power was lost.

What Mr. Froude has done for one particular case, I did in general in the pamphlet referred to in my paper. I may have been wrong in including too much, but if so, then for an orifice in a thin plate there is neither theoretical discharging force nor theoretical discharge, and if this be so, then the statement that the experimental discharge is about five-eighths of the theoretical quantity is absolutely meanless, for the theoretical force must either be the area of the outlet $\times$ by the head or by twice the head; there appears to be no medium between the two.

No rational explanation has yet been given of the supposed loss of about three-eighths of the power according to the common theory. I have given a simple explanation of the discrepancies between the deductions of my theory and experimental results; when some one has done the same with regard to the ordinary theory, it will then be time to discuss which is the right one, if either is right; but if neither is right, then, if mine is, as it has been called, "a monstrous absurdity," the common one must be a much more monstrous absurdity.

HINTS FROM AMERICAN ARCHITECTURAL PRACTICE.*

By WILLIAM FOGERTY, F. R. I. B. A.

A WRITER in the *Times* a few years back, remarked on the cosmopolitan character which attaches to some professions as compared with others that are of necessity more localized. As instances of the latter he adduced the law, which, however brilliant may be the prospects it holds out to its successful votaries, has its fields for exertion limited by the differing systems of jurisprudence which prevail in different countries. A Dublin barrister or solicitor, if obliged to transfer his sphere of practice to New York, or even to Quebec or Melbourne, would find a large part of his knowledge and experience of little use. Not so, however, with a physician or surgeon, whose knowledge of the human frame and its ailments would be of equal service in any part of the world. These latter professions accordingly are classed as cosmopolitan, and in the same category the writer above mentioned reckons our own and the kindred one of the engineer. As the laws of matter and motion and the principles of taste are the same all over the word, the architect or engineer, provided he be originally possessed of adequate capacity, will be in no way disconcerted by having a new field of practice open before him, but having devoted a brief space to acquire a knowledge of the local materials, will find his old training and experience of the fullest value in enabling him to utilize them. Differing requirements of climate and custom, so far from being obstacles in the way of a competent architect, will rather suggest to him new modes of construction and forms of design, and make it less difficult for him to achieve something novel, than where the conditions to be observed are unvarying. And it is hard if the practice of architects who have thus labored to transplant European architecture to the soil of other continents, does not suggest to them at least some few ideas which might with advantage be engrafted on home practice also. It is to the consideration of some such, suggested to the writer during nearly three years' residence and practice in the United States, that your attention is invited this evening.

In a former paper* on American Architecture, I referred to the fact that American town houses formed by far the most satisfactory class of buildings to be seen on that continent. The conditions of social life which prevail there have led to their development to a greater extent than is now usual in most of our cities, and may be compared in their results to those which at one period of our history caused Dublin to be filled with stately town mansions, now, alas! deserted by their lordly occupants, and relegated to the uses of schools, warehouses, charitable institutions, and government offices. The town houses of the American cities are nearly on the same scale as these once aristocratic mansions of ours, but are finished and fitted up with a modern completeness fairly commensurate with the general advance in the industrial arts which the world has made in the interim. One of the most noticeable features about them (which applies also to other classes of building) is the completeness of their systems of heating. This has doubtless been enforced by the rigor of the climate in winter, and necessity has proved here, as in so many other instances, "the mother of invention." Compared with the imperfect and wasteful manner in which our houses and public buildings are warmed, one is led to the conclusion that the mildness of our winter has allowed us to fall into utter supineness and neglect on the subject. And yet we have plenty of cold and, what is worse, damp weather here to make it important for us to attend to it. What can be more preposterous than to find the halls, staircases, passages, and often the bedrooms of a house or hotel destitute of any provision for warming them, and consequently filled with as cold and damp an atmosphere as prevails outside, while a few of the living rooms are warmed by

* A paper read before the Architectural Association of Ireland, January 27th, 1876.

* Van Nostrand's Magazine, January, p. 61.

open fireplaces only, which just give a comfortable seat or two in their immediate vicinity—the traditional "chimney corner,"—and which are certain to draw powerful currents of cold air towards them whenever the doors are opened? The effect of this defective system, or rather want of system, is seen in our internal domestic architecture, which is cramped or confined as compared with either American or continental European. Our doors are miserably small, and have to be placed in lop-sided positions, with a total disregard of symmetry. Draughts have to be guarded against by frequent cross door-ways, and the most careful adjustment given to the relative positions even of articles of furniture in the rooms, as may be seen by the planning in Professor Kerr's "Gentleman's House," simply to make what was originally bad tolerable.

Now, in the American houses and hotels, the moment one crosses the threshold he enters a mild and equable temperature, which prevades every part of the house, and permits the internal doors all through to be left open or shut independently of any considerations of temperature. It also permits of much more spacious and symmetrical doorways being used than with us; and, in fact, one of the most striking features to a British islander, on his first arrival, is the superior dimensions and elegance of the doorways, which are generally nine feet or ten feet high, and six feet or eight feet wide, circular-headed, in two leaves, either folding or sliding. The details of the methods by which this equable temperature is maintained vary somewhat, and to discuss them properly would require a volume by itself. Vast advances have been made in them during the last few years, so as to obviate most of the objections which have caused so much prejudice to exist amongst us against any other system of heating but the open fire-place. For example, some years back the use of stoves in American houses was very general, somewhat like those we see still on the continent of Europe; the dry, sulphurous heat evolved by them was very disagreeable, and they were denounced by Mr. Anthony Trollope and other English travelers as being the chief and, as he calls them, "accursed" means of destroying the complexions of the American ladies. Be that as it may, such stoves are no longer to be seen in well-appointed American houses. They are now heated either by a hot-air apparatus in the basement, or more commonly in the "sub-cellar," communicating by means of flues with openings into each important room, or else by steam; not so often by hot water. In fact, steam heating seems to have been brought to greater perfection there than anywhere else I know of, and as it admits of much smaller pipes being used than with water, and does not take so long to circulate, it possesses great advantages, and is well worthy of further attention at this side. The chief volume of heated air is arranged to be thrown into the halls and passages (the coldest parts with us), and in order to its diffusion to any rooms which may not have special connection with the apparatus, such as smaller bedrooms and closets, fanlights moving on hinges, are placed over all the doorways—an arrangement equally serviceable for diffusion of light as well as air. The upper panels of doors are also very often of ground plate-glass, in ornamental patterns, which is not only very elegant in appearance, but secures that the corridors and passages enjoy much better light than they would otherwise have. The halls, stairs and passages are handsomely furnished and carpeted, and are generally quite as agreeable lounging places as the sitting-rooms, to which they are thrown open by the large folding doors already referred to, to a much greater extent than prevails with us.

A comparison of the plans of some American houses herewith submitted, and an inspection of some of the details of internal doorways, will show the operation of these causes. Under a mode of heating by open fireplaces only, such plans and details would be inadmissible; but when once a proper system of general warming is applied, the architect is at liberty to deal with his internal plan and details in a much more symmetrical and spacious manner than before.

It will be observed also that the open fireplace is still retained in the principal rooms; nor do I by any means advocate its discontinuance. I regard it, however, as a useful supplement to a more com-

prehensive system of heating which ought to be contrived for every well-planned dwelling house or public building. And no such system should be adopted without at the same time arranging for a complete system of ventilation.

The next point to which I shall advert is the extent to which plumbing and engineering are applied to buildings, and especially dwelling houses, so as to obviate the necessity for a large number of servants and the use of detached pieces of crockery ware in the bed and dressing rooms. To this, too, the Americans have been led by the difficulty of procuring competent domestic servants. This is indeed the great trouble of American housekeepers, and drives so many respectable people to live in hotels and boarding-houses rather than in their own homes, but besides this it renders it important that houses shall be contrived so as to require the least possible number of servants to attend to them. And I am not clear but that we are coming to a similar set of conditions here. The cost of domestic service has largely advanced with us during the last few years, and still the complaint of householders is that really good servants are hard to be obtained at any price. In the mean time great advances have been made both with us and the Americans in the mechanical arts, in plumbing and engineering especially, and all our great cities are now blessed with an abundant supply of water; so why should we not advance with the times, and cease to entail upon our housemaids the necessity of carrying water, and filling and emptying ewers and basins by hand, which can all be accomplished almost instantaneously by a few simple and well understood arrangements?

In every well-appointed American house each bedroom or dressing-room has a fixed basin-stand (and often a bath) provided, to which hot and cold water are constantly laid on. Besides the constant saving of service effected by this, there is a great saving of time and increase of comfort, and the supply is much more plentiful than when it has to be brought up by hand. There is also a great saving in furniture, and I venture to say the cost of detached basin-stands and crockery ware all through a house would go a long way to defray the expense of fixed appliances such as the Americans use. The completeness and elegance with which they are fitted up leaves nothing to be desired, and the regularity with which they work, even through the hard frosts which prevail there, proves conclusively the high degree of perfection to which they have developed the plumber's art, and should encourage us in the endeavor to introduce such an obvious and desirable improvement here.

While referring to furniture, I am led to notice another particular in which American houses furnish us with a useful hint, namely, that a large number of things which with us form separate and cumbrous pieces of furniture, costly in themselves, difficult of removal, and often impossible to arrange comfortably in a room, are with them planned and built with and into the house. Of this class especially are bookcases, sideboards, mirrors, presses and wardrobes, plate-chests, and ice-boxes or refrigerators, which, when thus contrived, can be fitted into numerous spaces otherwise likely to be wasted, and can be also, and are in America, designed and executed in harmony with the general finish of the interior of the house. Now surely this arrangement is well worthy of imitation. What can be more absurd than, when once the architect has issued his final certificate and the builder has departed, to see huge vans disgorging loads of heavy articles of furniture at the door of a new house, often utterly out of character with its architectural style, and often also impossible to be fitted into the rooms, without blocking up doors and windows, while numberless tidy recesses remain in the mansion blank and bare, which, by a little judgment and forethought, might be handsomely and neatly fitted up so as to dispense with the necessity of heaving in these huge and unwieldy masses? I believe true economy in this case, as in the last, is decidedly in favor of the American practice, and the possibilities of artistic effect and completeness even more strongly so. Great variety and symmetry can be given to the forms of rooms by the judicious planning of such things as I refer to, which, as they will be required sooner or later, might as

well be designed and arranged by the architect, and executed under his direction, as ordered from some cabinetmaker independent of him, and often totally at variance with the character of his building.

I might include amongst the mechanical appliances which the Americans have brought into use with much skill and effect in their town houses, lifts or elevators for dishes and luggage. Every well-appointed house in New York has one or more of these, from the kitchen to the serving-room as a matter of course, and also from the basement or entrance-hall to the attic, for luggage. These, as well as the plumbing work already referred to, having become general, have been gradually improved so as to approach as near as possible to perfection in their operation. The same may be said of passenger elevators, which are in extensive use in all the American cities, and with which, of course, we have some practical acquaintance here; but it must be admitted that ours are not to be compared to those in use in America, either in the extent to which they are applied, or in the simplicity and smoothness of their working.

Another noteworthy instance in which the Americans have brought both mechanical skill and artistic taste to bear on domestic architecture, has reference to the style of their hinges and other door furniture. The forms of these customary with us and the manner in which they are applied, are both essentially commonplace and unartistic. What can be more disagreeably matter-of-fact than an ordinary butt hinge, except, indeed, the transparent fiction usually attempted by the house-painter, who generally tries to paint or grain it over as if it was part of the woodwork of the door? Whenever a door or pair of doors is wanted to fold right round, there seems no better means of accomplishing this result than by using double width butt hinges, projecting in all their hideous nakedness beyond the architraves. Since the revival of Gothic architecture there has been, to be sure, some attempt to introduce an artistic element into hinge-work, though even here it is too often confined to planting on sham branches, the butt hinge keeping its own place; but in our classic architecture the subject remains untouched. Now compare this state of things with the forms of hinges intended for and used in ordinary house-work, and bear in mind the fact that these are usually silver-plated, and kept brightly burnished, and you will agree with me, I think, that in this particular the Americans are, as they put it themselves, decidedly "ahead of us." The effect of these hinges shining on the dark polished walnut in general use for the doors and architraves is very fine, reminding one very much of jewelry on a lady's silk dress. As I understand, the American manufacturers are now turning out hardware at prices such as to compete fairly with Birmingham or Sheffield, and certainly the forms of their hinges and other door furniture are far superior to anything to be had from those places—I think it would be worth while for some of our enterprising hardware merchants here to open communication with some of them, and let us have the opportunity of trying their work on some of our buildings.

The finish of the stairs in American buildings is much more elaborate and artistic than is usual with us; and here, too, we may derive some useful hints. Look for a moment at the ordinary finish of stairs with us. Sir Gilbert Scott, in his work on "Gothic Architecture, Secular and Domestic," thus describes it:—"An ordinary staircase such as people are in the habit of dubbing 'handsome' without thinking it so, is after all a very dull thing: your neat steps with moulded nosings—with neat cast-iron or bronze balusters and French polished mahogany rail screwed round like a *cornu-ammonis* at the foot, is an excellent thing in its way, and far be it from me to say a word against so time-honored a contrivance. Let us speak well of the bridge which carries us safe over the stream, and on the same principle think gratefully of the staircase which conducts us so pleasantly to the drawing-room. All I have to say against it is, that with all its practical good qualities, there is a sleepy, self-satisfied look about it which no one would like to disturb." . . . . . "It does its duty so well, and so neatly and unobtrusively, that it is really a shame to find fault with it; all that I ask is to give it a fillip just to make it brush up and look more lively." He then pro-

ceeds to advise how Gothic, and especially Elizabethan, architecture afford opportunities for improving on this type by the use of a "bold moulded string carved—the stately newels surmounted possibly by figures—the massive rail moulded to fit well to the hand—the balustrade formed either of individual balusters, arcading, tracery, or of continuous open scroll-work;" also "by the introduction of inlaid woods, a mode of enrichment too much overlooked in our Gothic works."

Now all these valuable ideas have been apparently well known to and acted on by the Americans for a long time past, and that, too, without departing from the spirit of Classic or Renaissance architecture, which as yet is their favorite. The stairs of American houses are really beautiful and elaborate pieces of work, usually intrusted to a specialist in that line, called a "stair builder," who apparently has far distanced his progenitor, the "staircase hand," amongst ourselves.

The external doorways, especially of the town houses, next demand notice, as they form very imposing and attractive features in American houses, while so miserably bald and uninviting with us. I am inclined to think the architects or builders who erected the many stately aristocratic mansions of the past age in Dublin, already referred to, had much better ideas on that subject than those which have since become prevalent. At least, if we look about for a dignified and effective doorway, we are far more likely to hit on one of them than on one of our newest productions. There are bold and effective doorways to Powerscourt House (now Messrs. Ferrier and Pollock's), Charleville House (now the Roman Catholic University), and Avonmore House (now the United Service Club), also to many other old mansions; but the builders of more recent town houses seem to have had no better idea of a principal entrance-door than a plain semi-circular or semi-elliptical arched opening. The American town houses, small and great, have nearly always handsome doorways, with more or less of architectural character, and of spacious dimensions, the outer door in two folds opening at right angles to the front, and forming a most useful and inviting recessed porch, with a pair of inner glazed doors within. The paneling and mouldings are really elegant and varied, instead of the regular old four-panel or six-panel that we ought to be sick of by this time, and the material commonly oak, walnut, or other ornamental hard wood. I am aware that a prejudice exists here against anything like style in a hall-door, as looking too much like a hotel or club-house, just like what once existed against plate glass, but it is one which deserves to be discountenanced. There is certainly much room for improvement; but the scarcity of oak or other hardwood with us makes it unlikely that we shall ever rival the Americans in this particular. It is doubtful, however, whether our damp climate is not adverse to the use of any unpainted wood in such a position—at least any instance where oak or mahogany have been used for external doors in Dublin are far less satisfactory than where painted or grained deal was used—a remarkable instance in which the imitation is more lasting than the reality.

There is another very common feature in American domestic architecture, more frequent, however, in the country and suburbs than in the towns, which at first sight might seem deserving of adoption here, namely, the verandah. These are extensively adopted as affording cool and airy places of retreat from the sun; and although we are not generally favored in this latitude with a super-abundance of the rays of that luminary, similar places of shelter might seem to be desirable as protecting from rain, which is so frequent with us. I believe, however, experience is against the general adoption of such adjuncts here, unless to a very limited extent. If we could only be sure that the rain would always come down vertically, they would be of some value; but as unfortunately it is so addicted to driving in nearly a horizontal direction, and sometimes assumes the form of a drizzling mist which apparently defies the ordinary laws of gravitation, an open verandah presents a very uncomfortable place of shelter. I have seldom known them added to houses in this country without sooner or later having to be glazed in. I think, therefore, this feature, however pleasant and attractive it appears in American

country houses, is one to the extensive adoption of which the climate of this country is decidedly unfavorable.

The planning of American town houses is deserving of some attention, as rather different from our regular types, and presents some advantages. That form known as the "high stoop" has many elements in common with that of the terraces of middle-class houses in our own suburbs, both having high flights of steps to the hall-door, with a basement nearly level with the street. I think, however, the Americans have developed and improved this plan considerably. The hall and staircase, it will be observed, are thrown into one, and the latter arranged to ascend in one flight for each story; also much greater depth from front to rear given than in our houses,—the middle space being devoted to hall and dressing-rooms, lighted by a large skylight over the stairs, also by the extensive use of glazed panels and fanlights. Possibly such a disposition would be deficient in light with us; but, either from the superior brilliancy of their sunshine, or the effect of the other arrangements above described, it rarely seemed deficient in that respect there. One important advantage of the plan is, that it brings the kitchen and dining or breakfast rooms into very convenient proximity, and enables the business of the house to be performed with a minimum of servants.

There are two peculiarities of American architecture which can scarcely be passed over in a paper of this kind, but which, however successful they may be in that country, are not likely to be so here. I refer to the extensive use of wood in country houses, and of cast iron in warehouses and shop-fronts. Both these materials would be so costly here as to present no advantage, and the type of design which has developed from their use in America is not likely to find favor with us. It should be noted, however, that, particularly in the use of cast iron, the Americans have attained to a high degree of skill, and that I fear it would be a long time before our ironfounders could undertake the production of architectural forms with anything like the beauty and accuracy of their work.

American church architecture, I regret to say, furnishes but few hints to the European architect, unless it be to point out to him "what to avoid." Their most recent churches may be divided generally into three classes—

(*a*) Direct imitations or reproductions of English mediæval churches; seldom correct, however, either in plan or detail.

(*b*) Tabernacles or meeting-houses without any architectural pretension, but often well contrived and arranged for seeing and hearing.

(*c*) Attempts to combine these two discordant ideas, resulting commonly in all manner of shams and devices, to make what is a tabernacle within look like a Gothic cathedral without.

Of these three I need hardly say I consider the unadorned tabernacle by far the best, as having at least the merit of answering its purpose honestly. The last idea I look upon as the worst of all, but it is decidedly the most in fashion just now, most of the new and costly churches of New York being built in accordance with it, and of course lauded to the skies by the newspapers as noble structures, combining all the dignity and grandeur of the old world with the life and progress of the new. Imagine interiors like Spurgeon's Tabernacle, the Gaiety Theatre, or the Merrion Hall clothed in exteriors somewhat resembling Westminster Abbey or St. Patrick's, and you will form some idea of the effect.

There is, perhaps, one respect in which the arrangements of American churches are deserving of commendation, and that is in the comfortable manner in which they are furnished and fitted up. This is surely deserving of notice here, as whatever of comfort we may enjoy in our own homes, there is but little in our places of worship. The American churches are nearly always handsomely and uniformly carpeted and upholstered, not according to the individual means or fancy of the pew-holders, as with us. Why the committees of our churches should not have proper and uniform upholstery provided in our churches as well as they provide the seats themselves, I cannot understand. As it is, how absurd to see one pew or seat handsomely cushioned and carpeted, the next bare, and the next again half-and-half! Now

that we are come to the voluntary system—which, I need hardly say, is universal in America—and that every person pays for his church accommodation just as he pays for any other good thing, it is worth while for those who have the care of our churches to see that they are made a little more comfortable and attractive, without presenting such ugly contrasts as those just alluded to.

The same observation applies to some extent to the theatres, which in America are furnished and fitted up in a manner to put us to shame. When we shall see any improvement in that respect, cannot be predicted, but I fear the date is very far off.

I trust that these few hints derived from American practice may not be deemed unworthy the attention of this Association.

THE VIENNA WATERWORKS.

From "The Engineer."

A MORE striking illustration of the fallibility of theory, unless based on the data of experience, and of the irresponsibility of bodies corporate when entrusted with the execution of great undertakings, can hardly be conceived than the present failure of the waterworks of Vienna to supply the requirements of the city. Nature in her earliest efforts produced a site which, for beauty of scenery and advantages of position, can scarcely be surpassed; the first settlers from Rome, in founding the city of Vindobona, exhibited that admirable facility of adapting themselves to an adopted soil, utilizing every stream and mountain, every valley and plain, either for their defence or comfort, for supplying the necessaries or for getting rid of the impurities of life, in a manner which will hand down the memories of their engineers as ornaments of their time and worthy of imitation in the future; but it has been left to the representatives of the present generation, in copying the magnitude and massiveness of the Roman aqueducts, to ignore the foresight and skill which devised them, to stultify the efforts of nature herself by an error of calculation as to the adundance of her supplies, and, after an enormous expenditure of time and money, to be obliged *tacitly* to confess—for bodies corporate have only tongues for self-laudation—that the springs have failed to supply the quantity of water they had hoped for. Were the water supply of towns a question as unsolved as the utilization of our sewage, some excuse might be found for a partial failure in so large an undertaking; but with the histories and relics of past ages at their command, and the numerous examples of modern time free to their inspection, to say nothing of their own experiences from 1835 to 1857 in endeavoring to obtain filtered water from the Danube, when two and twenty years and 1,630,000 florins were expended in obtaining a result which had been calculated to cost 776,000 florins and be completed in eight years, there is neither room for excuse nor for palliation; and in endeavoring to gauge the want of perspicacity and the complacency which ignored the examples of the past, our imagination is lost in astonishment, our speculations in bewilderment.

It is true that Vienna at the present moment possesses one of the finest acqueducts of modern Europe, and the water which is brought by it from the icy springs of the Schneeberg to the city is, as far as it goes, the very best of its kind. Every praise is due to those who conceived, and to those also who executed the actual works; there lacks but one element to make the whole complete, and that unfortunately is the very essence of the purpose for which the money has been spent. The original contract for the execution of the works was 12,175,484 florins, but from a variety of causes incidental to theoretical estimates, a further sum of 42 per cent. has been expended; and on this point the inhabitants of Vienna have much cause to be thankful. Judging from the miserable blunders made in determining the thick-

ness of the pipes required to withstand the pressure, and from the indecision which in several cases—notably in that of the principal main entering the city from the reservoirs—caused the mains to be twice taken up and relaid, a much larger deficit would not have astonished the general public. In speaking of the requisite supply the official report naively says, "The actual quantity of water required for drinking and household purposes depends entirely on the number of inhabitants to be supplied—a calculation which is not very difficult to make." From a feeling of justice it must be admitted that this "not very difficult question" was solved without an error, and it was computed that the wants of the city, making the usual allowances for an increasing population, require for the present about ten million gallons daily during the summer, and 6,900,000 gallons during the winter months.

From observations made from month to month during the period 1865-1869 at the two sources from which the supply is drawn, it was found that the average lowest flow of water was during the month of January, viz., 5,312,000 gallons, and the highest in the latter end of April and the beginning of May, amounting to more than 20,000,000 gallons, strong presumptive evidence that the former is the result of frost, and therefore liable to a considerable reduction during a severe winter, the latter that of the melting of the snow. Notwithstanding the ascertained fact that the springs only yielded the desired quantity of water from the beginning of March to the end of November, and the utter impossibility of the reservoirs, constructed to hold a maximum of 1,617,317 gallons, being of any material assistance in supplementing the deficiency, the doubts and openly expressed fears of the uninitiated were laughed to scorn, and the missing factor by whose powers of multiplication the deficient quantity was to be made good fished up from the depths of some hitherto unknown axiom; or perhaps those in authority, relying on the problem of chances, or, still more likely, actuated by an unseemly haste to close the unfortunate year of the Exhibition with the completion of some work that bore on its front at least the semblance of success, totally ignored these untoward facts, and, allowing the wish to stand father to the thought, determined to go on with the scheme as it stood, and leave the probabilities of the future to repair the errors of the past. Retribution, however, has followed in haste on the footsteps of folly, and within less than three years from the festive opening, when the water first rose in a splendid jet from the fountain on the Schwarzenburg Platz to inaugurate the completion of the works. Nature has resented the unauthorized demands on her resources, and vindicated, by her refusal to overtax her energies, even at the bidding of the engineers of the Vienna community, the unerring laws by which she is regulated and the truth of the data she afforded for a basis of calculation. The quantity of water brought to the city during the past months has been so much less than was expected—indeed, the daily supply at one time scarcely exceeded 2,500,000 gallons—that the authorities have been continually obliged to fall back on the old filter beds of the Kaiser Ferdinand Waterworks, which draw their supply from the Danube Canal, a few hundred yards below the outflow of the main sewer of the town of Nussdorf and its surrounding villages, to supply even the small proportion of dwellings in which the pipes have been laid. It is scarcely reasonable to expect that the public, although accustomed for years to depend on this supply, with the exception of a few insignificant springs and the wells which until lately were to be found in many of the old houses, should, after being heavily taxed for a supply of pure water, rest content to find at odd times, without any previous notice being given, that the supply of delicious water, having a maximum temperature of 45 deg. Fah., has suddenly failed and been replaced by an inferior kind whose maximum temperature is 59 deg. Fah., and its maximum 70 deg. Complaints on all sides are loud and bitter, but so long as works of this kind are undertaken by public bodies who, having no individual responsibility, are amenable to no jurisdiction, there is but small chance of redress. Were there but the probability that the blunders of the present might lead to increased carefulness in the future, or that a succession of errors might culminate at

last in accumulative success, the prospect would afford some slight glimpses of hope; but so long as there exists a numerous body of partisans ready at all times to sacrifice their integrity, by ignoring or explaining away the failures of those from whom they hope to derive future benefits, or until the profession establish among themselves a technical "Vehm-gericht," whose verdict of censure on every mistake by which the public money has been squandered shall act as a "veto" on the future employment on public works of any one by whom the mistake has been made, be he whom he may, from the oldest member to the youngest student, until he shall give sufficient evidence from the actual execution of private works that he has redeemed his professional status, it is to be feared that care of the public interest and individual feeling of responsibility, which ought to stand first in the code of honor of engineers, will ever remain second to personal interests, and instead of manifesting that confidence which is absolutely necessary to insure the means of executing large undertakings, the public will rather content themselves with the appliances that satisfied their forefathers than attempt the dubious benefits of improvement.

NOTE ON THE RESISTANCE OF MATERIALS.

By Prof. ROBERT H. THURSTON.

Transactions of the American Society of Civil Engineers.

I had the pleasure of presenting to the Society, November 19th, 1873, a note in which I made known the discovery of an increased power of resisting stress which was developed in iron and steel, by their subjection to a strain which produced distortion beyond the elastic limit and gave them a set. This was more fully considered in a paper read April 4th, 1874, and the phenomenon more thoroughly examined in its bearings upon the practical work of the engineer, and the experimental researches by which its nature had been revealed were described. Subsequently Com. L. A. Beardslee, U. S. N., discovered the same principle independently and by a different method of experiment, and since the republication of these facts in foreign periodicals, experimenters in Europe have announced the observation of similar phenomena under identical or similar conditions.

The writer, since the announcement of this important peculiarity in the behavior of metals, has made a very large number of experiments upon irons, steels and on various alloys, as well as other simple metals, and upon many qualities of each. The mechanical laboratory of the Stevens Institute of Technology has been called upon to test large numbers of specimens of commercial qualities of nearly every kind of metal used as a material of construction, and these often furnished opportunities to pursue the investigation. The special work now in progress under the direction of the United States Board recently appointed to test iron, steel and other metals, has been particularly useful in permitting the examination of the behavior of the copper-tin alloys.

The results of observation, so far as the experience of the writer has now extended, may be briefly summarized as follows:

In iron, an elevation of the elastic limit very generally occurs under stress, to a marked degree. It is very variable in maximum amount, and in the time required to produce it. Some metals exhibit it to an almost imperceptible extent after long exposure to strain; other irons experience a great increase in their power of resistance to stress within the new elastic limit, and its development may sometimes be the result of but a very brief period of exposure to the action of that molecular re-arrangement which seems to be the cause of this phenomenon. The maximum increase noted by the writer is about thirty per cent., and the time required for its develop-

ment has sometimes not exceeded a half minute; in other cases, the elevation of the elastic limit has been scarcely perceptible after several days.

In steel, the same variation in the amount and in the time needed for its development has been noticed.

In the various other metals and in the alloys this action has not been found to occur in any case where the material was inelastic; on the contrary, it has been found that inelastic metals—particularly tin and metallic alloys of similar mechanical properties—have, when exposed to constant stresses exceeding their so-called elastic limits, gradually and continuously yielded by a process of flow which, in some instances, was observed to proceed uninterruptedly for days together, and would apparently have continued until fracture ensued, could the experiment have been carried to that extent.

These experiments have led the writer to suppose, as intimated in the paper referred to, that the force of cohesion and that force which gives stability of form to solids and distinguishes them from liquids—a force called by Prof. Henry "polarity"—are quite distinct modes of molecular action. Some materials—as the stronger of the ductile metals—exhibit great cohesion, and yet may flow under the action of a constant force, as in the cases last referred to above; while others—for example, over-hardened steel—may have great polarity, and consequently great stability of form, while exhibiting a relatively low power of cohesion.

It is in metals which belong to the latter class, rather than in those of the former character, that the elevation of the elastic limit by strain is observed The explanation already proposed, that this apparent increase of resisting power is really a consequence of the relief of internal stresses due to methods of manufacture, or to circumstances which have, by external application of force, prevented such a molecular arrangement of particles as would naturally take place, still seems to the writer the most satisfactory explanation. The close relation of this action to that observed by Prof. Johnson, thirty years ago, and illustrated by the process termed by him "thermo-tension," has been pointed out on a former occasion.

During the two years which have elapsed since the first announcement of the phenomenon of the elevation of the elastic limit by strain, a large mass of valuable data has been accumulated, which may at some future time be collated. In no case, in the whole range of these researches, has any indication been observed of a reduction of resisting power during the distortion of metal, between—on the one hand—the passing of the elastic limit, and—on the other hand—the point at which incipient rupture commences.

The writer is therefore led to conclude that the simple extension or straining of any member of any metallic structure, is not a cause of weakness, except where it produces an actual reduction of section resisting rupture, or where it brings the line of stress into a new direction in which it acts either with a larger component of force in the former direction of stress, or, as in the case of a reflexure of the metal, it takes the material at disadvantage strategetically, after a new disposition of its particles has taken place.

The conclusion seems also proper, that the elevation of the elastic limit by strain can only occur in metals which are elastic, and are capable of being placed in a condition of reduced resisting power by internal stress, by artificial or external force.

Finally; the conclusion has been arrived at, that structures are not weakened by stresses exceeding the elastic resisting power of their members, whatever the material of which they are composed, and even when made of metals having no elasticity and capable of yielding, like tin, by flow, unless such strains as are produced, are productive of actual molecular disruption.

THE RESISTANCE OF MATERIALS AS AFFECTED BY FLOW AND RAPIDITY OF DISTORTION.*

The effect of the "Flow of Metals" and of the force of polarity described by Prof. Henry, in modifying their resistance to external stress and their strain, was alluded to by the writer in preceding Transactions, as follows:

* Paper presented to the Society March 1st, 1876.

"The same molecular movement, or flow, which rearranges the internal force and relieves internal strain, may be a phase of that viscosity which Vicat supposed might in time permit rupture of metal subjected to stress nearly approaching its original ultimate resistance, the one action being a more immediate result than the other, and the latter producing its effect, even when cohesive force may have been actually intensified."

It was noted, however, that in all cases in which wrought iron and steel had been subjected to stress exceeding the elastic limit, the metal had exhibited no tendency to flow, and that, in nearly every case observed, an actual "elevation of the elastic limit by strain" had taken place. No experiment had then been made by the writer in which the same sample had exhibited both the elevation of the elastic limit by strain and the phenomenon of flow.

Since that time, when experimenting upon copper, strain-diagrams produced automatically have been observed to exhibit this double-effect. The elevation of the elastic limit has occurred in the earlier part of the test, and, at a later period, the strain-diagram exhibits flow, the metal yielding under a gradually decreasing stress. The progressive distortion which had never been observed by the writer in iron or steel, has, since the date of the paper, been frequently noted in other materials. For example, the following are a few illustrations:

(*See Table on following page.*)

Metals having a composition intermediate between these extremes have not been observed to exhibit flow or to increase deflection under a constant load.

Tests by tension with similar materials exhibits similar results, and these observations and experiments thus seem to confirm the remarks of the writer as above quoted, and to indicate that, under some conditions, the phenomena of flow and elevation of the elastic limit by strain may be co-existent and that progressive distortion may occur with "viscous" metals.

The paper referred to, enunciated a principle which had been deduced from experiments on wrought iron which is, if possible, of more vital importance to the engineer than the facts just given, viz: "That the time during which applied stress acts, is an important element in determining its effect, not only as an element which modifies the effect of the *vis viva* of the attacking mass and the action of the inertia of the piece attacked, but, also, as modifying seriously the conditions of production and relief of internal strain by even simple stresses."

It was then shown, by autographic strain-diagrams, that some materials yield the more readily the more rapidly the distortion and rupture are produced, their resistance varying in some inverse ratio with the rapidity of change of form. It was further suggested that this action might be closely related to to the opposite phenomenon of the elevation of the elastic limit by strain. An explanation was offered in the theory that, with rapid distortion, insufficient time is allowed for the relief of internal strain in materials capable of exhibiting that condition. It was further remarked that "the most ductile substances may exhibit similar behavior, when fractured by shock or by any suddenly applied force, to substances which are comparatively brittle," and illustrations were given of such behavior, and the precautions to be taken by the engineer, in view of this important modification of the resistance of materials by velocity of rupture, were stated.

The writer has continued his experimental researches, with occasional interruption, since that time, and has found the above given statements confirmed, and that relations exist between these phenomena of strain and the time under stress, which may properly be stated here as complementary of the principles already published in the two preceding notes which have appeared in Transactions.

Should it be true, as suggested by the writer, that the cause of the decreased resistance, sometimes observed with increased velocity of distortion, is closely related to the cause of the elevation of the elastic limit by strain, it would seem a simple corollary, that *materials so inelastic and so viscous as to be incapable of becoming internally strained during distortion should offer greater resistance to rapid than to slowly produced dis-*

TESTS BY TORSION.

Number of Test.	Material. Parts. Tin.	Copper.	Time under Stress.	Angle of Torsion.	Fall of Pencil.	Remarks.
1 } Same piece.	....	....	40 hours.	65°	0.06 inches.	Recovered after further distortion of 1°.
2 } Same piece.	100	....	1 hour.	180°	0.1 "	" in 8°.
3 } Same piece.	....	....	2 hours.	280°	0.1 "	" in 80°.
4	99.44	0.56	12 min's.	*380°	50 per cent.	Did not recover.
5	98.89	1.11	....	....	....	Behaved like No. 4.
6	Alloy.		....	58°	0.2 inches.	Did not recover.

TESTS BY TRANSVERSE STRESS—WITH DEAD LOADS.

SAMPLES 1×1×22 inches.

Number of Test.	Material. Parts. Tin.	Copper.	Load. Pounds.	Deflection Inches.	Time.	Increased Deflection. Inches.	Breaking Weight. Pounds.
7	....	100	600	0.534	5 minutes.	0.009	650
8	1.9	98.1	475	1.762	3 "	0.291	....
			500	2.108	3 "	0.488	500
9	7.2	92.8	950	0.348	5 "	0.081	1,350
10	10.	90.	950	0.395	5 "	0.021	....
			1,485	3.447	13 "	4.087	1,485
11	90.3	9.7	100	0.085	10 "	0.021	....
			120	0.14	10 "	0.055	....
			140	0.221	10 "	0.098	....
			140	0.319	10 "	0.038	....
			140	0.357	40 hours.	0.92	....
			160	1.294	10 minutes.	0.025	....
			160	1.32	1 day.	1.	....
			160	2.32	1 "	1.	....
			160	3.32	1 "	1.	160
12	98.89	1.11	90	0.243	5 minutes.	0.063	....
			120	0.736	15 "	1.055	....
			120	1.791	30 "	0.748	....
			120	2.539	45 "	0.595	....
			120	3.134	12 hours.	8.	120
13	100		80	0.218	5 minutes.	0.064	110

tortion, in consequence of their inability to "flow" so rapidly as to reduce resistance by such fluxion at the higher speed, or by correspondingly reducing the fractured section. This principle has been shown, by a large number of experiments, to be frequently, if not invariably, the fact. Copper, tin and other inelastic and ductile metals and alloys are found to exhibit this behavior, and are, therefore, quite opposite in this respect to ordinary wrought iron and worked steel.

The writer has noted the fact that very soft wrought iron does not always exhibit an observable elevation of the elastic limit by strain, and Com. L. A. Beardslee, U. S. N., has recently observed that the softest and most ductile specimen of iron yet tested by him at the Washington Navy Yard exhibited a perceptible increase of resistance with a considerable increase of rapidity of extension. This metal was peculiar in its softness and extreme extensibility. All the irons of commerce appear to belong to the other class.

* Taking elasticity line.

The records of the Mechanical Laboratory of the Stevens Institute of Technology frequently illustrate the proposition that metals which gradually yield under a constant load offer increased resistance with increased rapidity of rupture.

The curves of deflections of a considerable number of ductile metals and alloys are very smooth when the time during which each load has been left upon them is the same; but, whenever that time has been variable, the curve has been irregular. Bars of such metals broken by transverse stress give a greater resistance to rapidly increasing stress than to stress slowly intensified. Two pieces of tin from the same bar were broken by tension, the one rapidly and the other slowly. The first broke under a load of 2,100 and the latter of 1,400 pounds. The example illustrates well the very great difference which is possible in such cases, and seems, to the writer, to indicate the possibility in extreme cases of obtaining results which may be fatally deceptive when the time of rupture is not noted.

Autographic strain-diagrams, given by this class of metals, exhibit smooth, straight and horizontal lines for long distances on the paper where the distortion is produced by a uniform motion. Increasing the rapidity of distortion causes an immediate and sustained elevation of the pencil, and a decrease of velocity causes the line to drop to a lower level. In some experiments* a torsion of one revolution in a half hour, the test piece being five-eighths inch diameter and one inch long, just kept the pencil on a horizontal line.

Two tests pieces from the same bar were broken, the one rapidly, the other slowly. The former gave a strain diagram of which the maximum ordinate was about fifty foot pounds higher than the maximum of the latter, the difference being nearly fifty per cent. of the higher.†

It is evident that, whatever the character of the material and whatever the velocity of rupture, the effect of the *inertia* of the mass, and of particles not immediately affected by a shock, remains, and that its effect is *always* to reduce the resilience of the metal and its resistance to shock; and this reduction may, in many cases, more than compensate the increase of resistance here noted. Its tendency is always to produce a sharp fracture which, with such sudden blows as are given by cannon shot, for example, may resemble the break characteristic of brittle and non-ductile substances.

The writer would, therefore, divide the metals used in construction into two classes:

1st. Metals subject to internal strain by artificial manipulation and which may exhibit an elevation of the elastic limit by strain and decreased power of resisting stress under increasing rapidity of distortion. The ordinary irons of commerce are typical of this class.

2d. Metals of an inelastic viscous character, not subject to internal strain and not usually exhibiting an elevation of the elastic limit by strain and which offer increased resistance when the rapidity of distortion is increased. Tin is a typical example of this class.

It is obvious that the value of the former class for the construction of the engineer is vastly greater than the latter, and especially for permanent loads and low factors of safety.

The depression of the elastic limit has been observed previously in materials, but less attention has been paid to it than the importance of the phenomenon would seem to demand. The accompanying plate exhibits the strain diagrams produced by plotting the results of experiments.* They are selected as typical examples, and as representing the two classes of materials described.

In making the experiments the bar was mounted on cylindrical steel bearings, which were themselves supported on accurately planed level surfaces, and the deflection was produced by means of a powerful screw and a large hand-wheel. The weight was measured by a Fairbanks scale combination, and the deflections and sets by a special measuring apparatus† which reads to 0.0001 inch, with an error of 0.000741. Touch

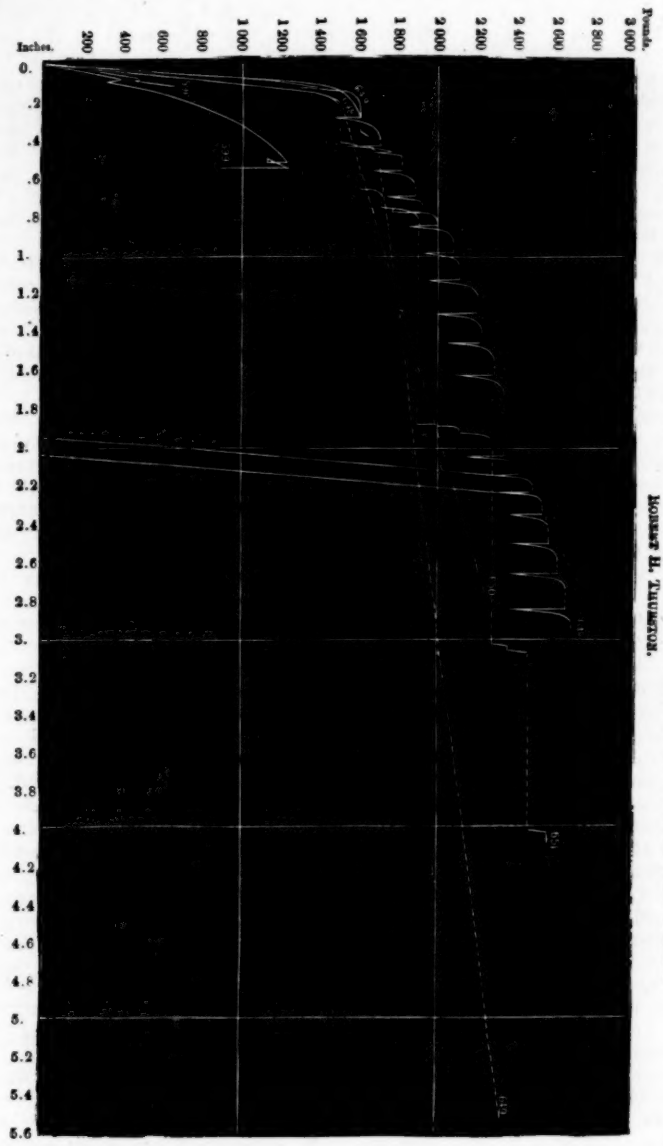
* Made for the writer with great care and skill by his assistant, Mr. Wm. Kent.

† The inertia of the *weight* in these examples has no measurable effect in modifying those results.

* Made and recorded in the Mechanical Laboratory of the Stevens Institute of Technology.

† Made to the order of the writer, by Messrs. Brown & Sharpe.

is indicated by a delicate Stackpole level. The measuring instrument was unaffected by the forces tending to distort the straining apparatus. The deflecting force was adjusted by the scale-beam. The bar being in place, the weight to be



STRAIN DIAGRAMS

OF FOUR BARS OF WROUGHT IRON, AND TWO OF COPPER-ZINC ALLOYS TESTED BY TRANSVERSE STRAINS.

ROBERT H. THURSTON.

put on it was set off on the scale-beam, and the screw was carefully turned until, by its pressure on the middle of the bar, the scale-beam slowly rose and vibrated about the middle of its range, which point was indicated by a pointer at the

end of the beam, traversing a fine lined scale on the frame. When the adjustment had become satisfactory, the deflection was read off and the beam usually released, in order that the set might be observed. It was then again deflected by a heavier weight. Occasionally the bar was left thus strained, and with a constant deflection, for a considerable period of time, and the change of effort exerted by it noted at frequent intervals. In all such cases the scale-beam gradually drooped, and a decreased effort to effect restoration of form was indicated. When the beam had fallen, the weight was pushed back until the beam arose and vibrated about the center line again, and the weight and time were recorded. This was repeated as the beam exhibited less and less loss of power of restoration, and when this decrease of effort no longer exhibited itself, a new series of deflections was produced.

The bar, No. 599, which was quite ductile, exhibited an unchanged law of relation of amount of deflection to intensity of deflecting force, and, as shown by the diagram, the curve representing its test pursued the same general direction after one of these "time-tests" as before.

The loss of effort at 163 pounds is seen to have been about twenty pounds, the deflection amounting to 0.0347 inches, and the effort falling from 163 to 143 pounds. At 403 pounds the loss of restorative force is about the same; the figures fall from 403 to 333 pounds, the deflection being held constant at 0.0886 inches, again from 333 to 302 pounds at a deflection of 0.0896, and still again from 1233 to 1137 pounds at a deflection of 0.5209 inches.

Before the bar, under further deflection, had quite regained its original resisting power, the "time-test" was repeated, the deflection amounting to 0.5456 inch, and the weight applied being 1233 pounds. The result noted was quite unanticipated. The effort steadily decreased at a varying rate, which is indicated by the diagram of time and loads, and the bar finally snapped sharply, and the two halves fell upon the floor. The effort had decreased to 911 pounds. The deflection was precisely what it had been under the load of 1233 pounds. The beam had balanced at 911 pounds for about three minutes when the fracture took place. An assistant was sitting fifteen or twenty feet from the machine at the instant, but no one had approached the machine after the last adjustment of the weight.

This is a case without parallel in the experience of the writer, and its conclusion indicates a possibility of depreciation in resisting power of the class of metals of which tin has been taken as the type, which depreciation, in the present state of our knowledge of the properties of such metals in this regard, it may be safest to assume to be a source of danger in some cases in which the load approaches the maximum resisting power of the piece. This illustrates the case of progression of flow until the section most strained has been weakened to the point of actual molecular disruption, which disruption would seem to have been here produced by the effort of other and less injured portions, to resume their original positions, and to straighten the two halves of the bar. It would seem that such action should be determined by flow occurring in a somewhat ductile but still somewhat elastic metal.

The strain diagram of this bar is seen to be nearly hyperbolic; but the law of Hooke, *ut tensio sic vis*, holds good, as usual, up to a point at which the load is about one-half the maximum. The curve of times and loads, exhibits the rate of loss of effort while the bar was finally held at a deflection of 0.5456 inch, the load being carefully and regularly reduced, as the effort diminished, from 1233 to 911 pounds, at which latter figure the bar broke. The curve is a very smooth one. The following is the record of the test:

(*See Table on following page.*)

The bar was left under strain at 11 h. 22 m. A. M., and the effort to restore itself measured, at intervals, as follows:

Hour.—11 h. 37 m.; 11 h. 50 m. A. M. 12 h. 2 m.; 12 h. 8 m.; 12 h. 25 m.; 12 h. 25 m.; 12 h. 39½ m.; 12 h. 53½ m.; 12 h. 58½ m.; 1 h. 20 m. P. M.

Effort.—1 133; 1 093; 1 070; 1 063; 1 043; 1 023; 1 003; 993; 911 pounds.

At 1 h. 23 m. P. M. the bar broke.

An example of somewhat similar behavior, but exhibited by a metal of very different quality, is shown on the next page (second table).

BAR No. 599.

90 parts zinc, 10 parts copper : 1 × 0.992 × 22 inches.

Load.	Inches.		Load.	Inches.		Load.	Inches.	
Pounds.	Deflection	Set.	Pounds.	Deflection	Set.	Pounds.	Deflection	Set.
23	0.0033	....	363	0.0781	....	3	....	0.0336
43	0.0078	....	403	0.0881	....	643	0.1641	....
63	0 0127	....	3	....	0.0079	803	0.2149	....
103	0.0225	....	403	0.0886	....	1,003	0.3178	....
143	0.031	....	Resistance	fell in 8 h.	30 m.	1,103	0.3921	....
163	0.0347	....	to 333	0.0886	....	1,203	0.481	....
Resistance	fell in 15 h.	25 m.	3	....	0.0246	1,238	0.5209	....
to 143	0.0347	....	333	0.0896	....	Resist	ance fell in	15 m.
3	....	0.0039	Resist	ance fell in	15 h.	to 1,137	0.5209	....
163	0.0391	....	to 302	0.0896	....	3	....	0.2736
203	0.0471	....	303	0.0876	....	1,137	0.5131	....
243	0.0544	....	403	0.1072	....	1,233	0.5456	....
283	0.0611	....	503	0.1282	....	....	....	....
323	0.0692	....	603	0.1521	....	....	....	....

BAR 596.

75 parts zinc, 25 parts copper ; Second Casting : 0.985 × 0.985 × 22 inches.

Load.	Inches.		Load.	Inches.		Load.	Inches.	
Pounds.	Deflection	Set.	Pounds.	Deflection	Set.	Pounds.	Deflection	Set.
23	0.0057	....	423	0.073	....	to 473	0.0866	....
63	0.0142	....	463	0.0799	....	3	....	0.0092
103	0.0207	....	503	0.0866	....	503	0.0894	....
143	0.0275	....	3	....	0.0014	543	0.0952	....
183	0.0346	....	503	0.0866	....	583	0.1012	....
223	0.0414	....	Resist	ance fell in	5 h.	603	0.1042	....
263	0.0485	....	to 489	0.0866	....	623	0.1075	....
303	0.0549	....	3	....	0.0074	643	0.1102	....
343	0.061	....	489	0.0866	....	663	0.1136	....
383	0.0669	....	Resistance	fell in 13 h.	30 m.	Broke 5"	after, with sound.	ringing

This bar was hard, brittle and elastic, but must apparently be classed with tin in its behavior under either continued or intermitted stress.

There seems to the writer to exist a distinction, illustrated in these cases, between that "flow" which is seen in these metals, and that, to which has been attributed the relief of internal stress and the elevation of the elastic limit by strain and with time.

This last phenomenon—the exaltation of the elastic limit by strain—has been observed very strikingly, by the writer, in the deflection of iron bars, by transverse stress. The plate exhibits the strain-diagrams obtained by transverse deflection of four bars of ordinary merchant wrought iron which were all cut from the same rod. Of these, two were tested in the machine above described, in which the deflection remains constant when the machine is untouched while the load gradually decreased — or, more properly, while the effort of the bar to regain its original form, decreases. The other two were tested by dead loads —the load remaining constant while the deflection may vary when the apparatus is left to itself. (The record is given on pages 262–264.

These two pairs of specimens were broken; one in each set by adding weight steadily until the end of the test, so as

to give as little time for elevation of elastic limits as was possible, and one in each set by intermittent stress, observing sets, and the elevation of the elastic limit.

If the long-known effects of cold-hammering, cold-rolling and wire-drawing, in stiffening, strengthening and hardening some metals can be, as the writer is inclined to believe, attributed in part to this molecular change, as well as to simple condensation and closing up of cavities and pores, this exaltation of the elastic limit by distortion under externally applied force, has now been shown to occur in iron and metals of that class in tension, torsion, compression and under transverse strain.

Referring to the plate, it will be seen that there is exhibited the action in the latter case even more fully and strikingly than in the record above given, and a study of these typical examples cannot fail to prove both interesting and instructive.

TEST OF WROUGHT IRON BARS BY TRANSVERSE STRAIN.

Samples 1 inch square, 28 inches long; 22 inches between supports.

No. 648. TESTED IN FAIRBANKS' MACHINE.

Load.	Inches.		Load.	Inches.		Load.	Inches.	
Pounds.	Deflection	Set.	Pounds.	Deflection	Set.	Pounds.	Deflection	Set.
103	0.0132	....	3	....	0.0246	1,877	0.6034	....
203	0.0244	....	1,329	0.1451	....	1,891	0.6626	....
Resistance	fell in 13 h.	35 m.	1,403	0.1522	....	3	....	0.4938
to 199	0.0244	....	1,483	0.16	....	1,891	0.7001	....
303	0.0342	....	1,523	0.1647	....	Resist	ance fell in	10 s.
403	0.0428	....	1,563	0.1761	....	to 1,801	0.7001	....
Resistance	fell in 1 h.	30 m.	1,603	0.2548	....	Resist	ance fell in	6 m.
to 399	0.0428	....	3	....	0.1091	to 1,737	0.7001	....
3	....	0.0042	1,603	0.287	....	Resist'ce	fell in 5 h.	23 m.
503	0.0528	....	Resistance	fell in 6 h.	3 m.	to 1,721	0.7001	....
603	0.0619	....	to 1.457	0.287	....	3	....	0.5406
Resist	ance fell in	4 h.	3	...	0.1451	1,741	0.7031	....
to 598	0.0619	....	1,457	0.2863	....	1,911	0.7246	....
803	0.0806	....	1,603	0.3016	....	1,921	0.7566	....
Resistance	fell in 15 h.	15 m.	1,703	0.3921	....	3	...	0.5746
to 789	0.0806	....	3	....	0.2431	1,921	0.7746	....
903	0.0907	....	1,703	0.4301	....	Resist'ce	fell in 21 h.	48 m.
1,003	0.0995	....	Resistance	fell in 20 h.	50 m.	to 1,767	0.7746	....
Resistance	fell in 5 h.	20 m.	to 1,541	0.4301	....	3	....	0.6028
to 987	0.0995	....	3	....	0.2846	1,767	0.7726	....
3	....	0.0049	1,541	0.4296	....	1,931	0.7876	....
1,203	0.1197	....	1,603	0.4346	....	1,995	0.8036	....
3	....	0.0071	1,711	0.4456	....	2,001	0.8266	....
1,203	0.121	....	1,753	0.4513	....	3	....	0.6451
Resist	ance fell in	2 h.	1,781	0.4651	....	2,001	0.8498	....
to 1,187	0.121	....	Resistance	fell in 6 h.	3 m.	Resist'ce	fell in 21 h.	30 m.
3	....	0.0096	to 1,661	0.4651	....	to 1,831	0.8498	....
1,203	0.1226	....	3	....	0.3106	3	....	0.6780
1,243	0.1266	....	1,675	0.4676	....	1,831	0 8471	....
1,283	0.1301	....	1,787	0.4808	....	2,003	0.8641	....
1,323	0.1354	....	1,811	0.5446	....	2,071	0.8819	....
1,363	0.1421	....	3	....	0.3771	2,081	0 9396	....
1,403	0.1504	....	1,811	0.5661	....	3	....	0.7576
3	....	0.0196	Resist	ance fell in	46 m.	2,081	0.9886	....
1,403	0.1522	....	to 1,675	0.5661	....	Resist'ce	fell in 21 h.	39 m.
Resist	ance fell in	3 m.	Resist	ance fell in	17 h.	to 1,871	0.9886	...
to 1,387	0.1522	....	to 1,161	0.5661	....	3	....	0.8148
Resistance	fell in 2 h.	25 m.	3	....	0.4081	1,911	0.9904	....
to 1,361	0.1522	....	1,661	0.5645	...	2,083	1.0106	....
Resistance	fell in 39 h.	5 m.	1,801	0.578	....	2,121	1.0496	....
to 1,329	0.1522	....	1,861	0.5866	....	2,131	1.0911	....

No. 648.—(*Continued.*)

Load.	Inches.		Load.	Inches.		Load.	Inches.	
Pounds.	Deflection	Set.	Pounds.	Deflection	Set.	Pounds.	Deflection	Set.
3	....	0.9021	2,351	1.7321	....	2,571	2.3854	....
2,131	1.1316	....	3	....	1.5196	2,591	2.4287	....
Resistance	fell in 47 h.	37 m.	2,351	2.0446	....	3	....	2.1952
to 1,869	1.1316	....	Resist	ance fell in	16 h.	2,591	2.5044	....
3	....	0.958	to 2,135	2.0446	....	Resist'ce	fell in 15 h.	4 m.
1,941	1.1358	....	3	....	1.8441	to 2,371	2.5044	....
2,131	1.1551	....	2,135	2.0431	....	3	....	2.2842
2,181	1.1686	....	2,355	2.0646	....	2,371	2.5022	....
2,201	1.1981	....	2,391	2.0736	....	2,591	2.5247	....
2,211	1.2356	....	2,411	2.1136	....	2,611	2.5334	....
3	....	1.0361	3	....	1.8964	2,631	2.5927	....
Resist	ance fell in	9 h.	2,411	2.1451	....	3	....	2.3577
to 1,997	1.2356	....	Resistance	fell in 8 h.	35 m.	2,631	2.653	....
3	....	1.1158	to 2,238	2.1451	....	Resist'ce	fell in 8 h.	2 m.
2,001	1.3016	....	Gradual	ly reduced	strain.	to 2,371	2.653	....
2,211	1.3226	....	to 3*	....	1.9266	3	....	2.4227
2,231	1.3656	....	Gradually	increased	strain.	2,371	2.6532	....
2,237	1.3936	....	to 2,238*	2.1336	....	2,631	2.6833	....
3	....	1.1946	2,411	2.1516	....	2,651	2.6992	....
2,241	1.4441	....	2,491	2.1811	....	2,661	2.7307	....
Resistance	fell in 13 h.	50 m.	2,501	2.2121	....	3	....	2.4987
to 2,041	1.4441	....	3	....	1.9886	2,661	2.8324	....
3	....	1.2538	2,501	2.2471	....	Resist'ce	fell in 61 h.	32 m.
2,041	1.4421	....	Resistance	fell in 14 h.	10 m.	to 2,363	2.8824	....
2,241	1.4631	....	to 2,295	2.2471	....	3	....	2.5924
2,281	1.4821	....	3	....	2.0331	2,363	2.8286	....
2,301	1.5216	....	2,295	2.2456	....	2,685	2.8627	....
2,311	1.5531	....	2,541	2.2762	....	2,701	2.871	....
3	....	1.3436	2,561	2.3102	....	2,710	2.8917	....
2,311	1.6166	....	3	....	2.0763	2,720	2.9297	....
Resistance	fell in 8 h.	8 m.	2,561	2.35	....	3	....	2.647
to 2,091	1.6166	....	Resistance	fell in 6 h.	18 m.	2,720	2.9692	....
3	....	1.4181	to 2,369	2.35	....	Resist'ce	fell in 5 h.	48 m.
2,091	1.6166	....	3	....	2.1402	to 2,483	2.9692	....
2,311	1.6466	....	2,369	2.3587	....	3	....	2.7357
2,341	1.6996	....	2,551	2.3782	....	Bar rem	oved : test	ended.

No. 649. TESTED IN FAIRBANKS' MACHINE.

Load.	Deflection	Load.	Deflection.	Load.	Deflection.	Load.	Deflection.
Pounds.	Inches.	Pounds.	Inches.	Pounds.	Inches.	Pounds.	Inches.
103	0.0139	900	0.0889	1,462	0.1505	In 2¾ m.	was 0.3629
200	0.0238	1,000	0.0982	1,480	0.1569	1,620	0.3704
300	0.0328	1,100	0.1081	1,500	0.1619	1,640	0.3831
405	0.0425	1,200	0.1171	1,520	0.1709	In 6 m.	was 0.4404
500	0.0519	1,300	0.1279	1,540	0.1804	1,660	0.4479
600	0.0602	1,400	0.1398	1,560	0.2078	1,680 (*b*)	0.4599
700	0.0689	1,420	0.1435	1,580	0.2429	....	....
800	0.0787	1,442	0.1472	1,600(*a*)	0.2854	2,350	5.577

* Gradually reduced strain to 3 pounds, taking a number of readings; then gradually increased it to 2,238 pounds, taking readings corresponding to former ones; found that increase of deflection was proportional to increase of load.

(*a*) At 1,600 pounds the beam sank instantly; ran the pressure screw down so as to keep the beam balanced for 2¼ m., with increase of deflection as noted. (*b*) At 1,680, ran pressure screw rapidly but steadily down, moving the poise along the beam to keep it balanced. The beam vibrated up and down, falling or rising instantly as the wheel was turned slower or faster. The resistance reached a maximum of 2,350 poonds, when the deflection was 5.577 inches.

No. 650. Tested by Dead Loads.

Load. Pounds.	Deflection Inches.	Load. Pounds.	Deflection. Inches.	Load. Pounds.	Deflection. Inches.	Load. Pounds.	Deflection. Inches.
100	0.015	400	0.0425	800	0.0858	1,400	0.1749
200	0.0229	600	0.0638	1,200	0.1456	1,500 (c)	0.2143

No. 651. Tested by Dead Loads.

Load. Pounds.	Deflection Inches.	Load. Pounds.	Deflection. Inches.	Load. Pounds.	Deflection. Inches.	Load. Pounds.	Deflection. Inches.
100	0.0158	In 5 h. 46	m. In 0.6598	In 48 h. 30	m. was 1.9245	2,452	3.0732
200	0.0275	1,700	0.67	2,222	1.9379	2,484	3 0812
400	0.0489	In 3 m.	was 0.6716	2,288	2.1386	In 39 h.	40 m. 4.2591
600	0.0709	In 16 h.	was 0.7615	In 12 m.	was 2.9535	In 43 h.	20 m. 4.2591
803	0.0913	1,800	0.771	2,266	2 9928	2,513	4.2623
1,000	0.1141	1,900	1.0904	In 17 m.	was 3.0157	2,556	4.267
1,200	0.1394	In 3 h. 15	m. was 1.8567	In 3 h. 37	m." 3.0236	In 4 h.	20 m. 4.2749
1,400	0.1701	In 45 h. 45	m. was 1.8709	2,288	3.029	2,589	4.2749
1,500	0.2465	2,005	1.8787	2,350	3.0426	In 48 h.	was 4.6591
In 8 m.	was 0.4307	In 3 h.	was 1.8819	2,370	3.0433	In 61 h. 30	m." 4.6701
1,600	0.489	2,052	1.8886	In 25 h. 15	m. was 3.0677	Weights reached support. Test was ended.	
In 6 m.	was 0.6504	2,115	1.8921	2,422	3.0701		

The strain-diagrams exhibited in the plate do not present to the eye one of the most important distinctions between the two classes of metals. As seen by study of these diagrams, both classes, when strained by flexure, gradually exhibit less and less effort to restore themselves to their original form.

In the case of the tin-class, this loss of straightening power seems often to continue indefinitely, and, as in one example here illustrated, even until fracture occurs.

With iron and the class of which that metal is typical, this reduction of effort becomes gradually less and less rapid, and finally reaches a limit after attaining which, the bar is found to have become strengthened, and the elastic limit to have become elevated. In this respect, the two classes are affected by time of strain, in precisely opposite ways.

The plate exhibits, even better than the record, the superior ultimate resistance of the bars which have been intermittently strained, as well as the elevation of the elastic limit. This parallelism of the "elasticity lines" obtained in taking sets, shows that the modulus of elasticity is unaffected by the causes of elevation of the elastic limit.

Evidence appealing directly to the senses has been presented in the course of experiment on the second class of metals, of the intra-molecular flow. When a bar of tin is bent, it emits while bending the peculiar crackling sound, familiarly known as the "cry of tin." This sound has not been observed hitherto, so far as the writer is aware, when a bar has been held flexed and perfectly still. In several cases recently, in experiments on flexure* of metals of the

(c) At 1,626, the reading was not taken. Weights as follows were rapidly added, 4 or 5 pieces each minute, as follows:—82, 25, 42, 15, 16 10, 15.5, 16, 25, 26, 25, 13, 11.5, 16, 27, 62, 40.5, 61, 45, 62=2,260.5 pounds. The bar sank rapidly, its side pressure splitting the wood which confined the mandrels. The set, measured after the bar was removed, was 2.5 inches. The total deflection is calculated as follows:—the elasticity of the bar remaining the same the increase of deflection over set is directly proportional to the load. (This is shown by the parallelism of the elasticity lines with the original line within the elastic limit.) Thus at 800 pounds, the set was inappreciable, deflection 0.0858; whence 800: 0.0858:: 2,260: 0.242 difference of deflection and set: set was 2.5, hence calculated deflection 2.742 inches.

* Made in the Mechanical Laboratory of the Stevens Institute of Technology.

second class, bars held at a constant deflection have emitted such sounds hour after hour, while taking set and losing their power of restoration of shape.

During some of the experiments made, a very marked illustration of the decrease of set with time, which has been observed and described by Prof. W. A. Norton, has been noted, and the recovery of straightening power in the deflected bar has sometimes been strikingly large, amounting to nearly thirty pounds in fifteen minutes. A record of one of these bars is—

BAR No. 563.

17.5 parts copper, 82.5 parts tin. 0.986 × 0.993 × 22 inches.

Load.	Inches.		Load.	Inches.		Load.	Inches.	
Pounds.	Deflection	Set.	Pounds.	Deflection	Set.	Pounds.	Deflection	Set.
10	0.0027	....	140	0.0804	....	300	0.4597	....
20	0.007	....	180	0.1343	....	5	....	0.3084
40	0.0153	....	200	0.1666	....	Set de	creased in	....
60	0.0256	....	5	....	0.0821	2 hrs.	20 min. to	0.2845
80	0.0365	....	200	0.1798	....	300	0.5332	....
100	0.0499	....	240	0.2503	....	310	Bar broke	in put-
5	....	0.0093	280	0.3762	....	...	ting on	strain.

After 300 pounds had been placed on the bar, and the reading taken, the screw was run back till the beam just balanced at 5 pounds, the pressure block attached to the screw just barely touching the bar. The set was then read, as above, 0.3084 inches, the beam slowly rising. The pressure screw was then run back till beam again balanced at 5 pounds, and the set measured 0.3022 inches. The time was 2 minutes. The beam again rose, poise on beam was pushed forward and balanced at 10 pounds; the time was 2 minutes. In two minutes more, beam balanced at 14 pounds. The pressure screw was again run back till beam balanced at 5 pounds and the set measured 0.0298 inches. The beam rose again; at 11 hours 37 minutes, A. M. In 2 minutes it balanced at 10 pounds, in 10 minutes at 16 pounds, and in 29 minutes at 23 pounds. The beam was again balanced at 5 pounds, set measured 0.2902 inches. The beam rose in 4 minutes. In 29 minutes the beam balanced at 14 pounds, and in 65 minutes more it balanced at 20 pounds. The beam was again balanced at 5 pounds and the set measured 0.2845 inches. The total decrease of set in 2 hours 20 minutes was 0.3084 − 0.2845 = 0.0239 inches.

Then replaced 300 pounds, and read deflection 0.5332 inches; increased the pressure, but the bar broke before 310 pounds was reached.

PRIME MOVERS.*

From "Nature."

I.

THE subject on which I have now the honor to address you, the subject which is to occupy our attention to-day, is that of prime movers; that is to say, we are about to consider that class of machines which, to use the words of Tredgold, "enable the engineer to direct the great sources of power in nature for the use and convenience of man."

Although machines of this kind are, in truth, mere converters or adapters of extraneous forces into useful and manageable forms, and have not any source of life, power, or motion, in themselves,

* Address delivered by F. J. Bramwell, C. E., F. R. S., at South Kensington.

nevertheless they impress us with the notion of vitality; and it is difficult to regard the revolving shaft of a water-wheel or turbine, set in motion by some hidden stream, or to gaze upon the steam engine actuated by an unseen vapor, without, as I have said, the idea being raised in our minds that the machines on which we are looking are really endowed with some kind of life.

The invention of such machines marks a very great step in the progress of mechanical science in the world, as it commences an era distinct from that in which mere machines to be acted on by human or animal muscular force were alone in existence. Machines such as these, highly useful as they may be, are, after all, only tools or implements more or less ingenious and more or less complex.

Mankind could not have been very long upon the earth before they must have found the need and must have discovered the utility of some kind of tool or implement; they must soon have found that the direct action of the power of the arm, which was not enough by itself to break up some obstacle, became sufficient if that action were applied by the wielding of a heavy club, or through the putting into motion of a large stone, and thus the hammer or its equivalent must have been among the earliest of inventions. Such an implement must soon have taught its users that muscular force could be exercised through a considerable space, could be stored up, and could be delivered in a concentrated form by a blow.

Similarly it could not have been long before it must have been found that to raise water in the hollow of the hand by repeated efforts was not so convenient a mode as to raise it in a bent leaf or in a shell, and in this way another implement would speedily be invented. We might pursue this line of speculation, and doing so we should readily arrive at the conclusion that (without attributing to the early inhabitants of the earth any profound acquaintance with mechanics) the hammer, the lever, the wedge, and other simple tools and utensils, must soon have come into existence; and we should also be led to believe that when, even with the aid of tools such as these, a man singly could not accomplish any desired object, the expedient of combining the power of more than one man to attain an end would soon be thought of, and that the requisite appliances, such as large beams used as levers, numerous ropes (which must very early in the history of the world have been twisted from filaments) and matters of that kind, would come into use. For a corroboration of this view, if one were wanted, the fact may be cited that on the discovery of any isolated savage community it always is found to have advanced thus far in mechanical art.

But passing from such machines as these, which are rather of the character of tools and implements, than machines, as we now popularly use the word, one knows that even complicated mechanism for the purpose of enabling muscular force to be more readily applied, is of very ancient date. On this point I will quote from only one book, that is the Bible, where, at the 10th and 11th verses of the 11th chapter of Deuteronomy, a statement is made clearly indicating that in Egypt irrigation was carried on by some kind of machine worked by the foot; whether the treadwheel with water-buckets round about it mentioned by Vitruvius, or whether the plank-lever with a bucket suspended at one end and worked by the laborer running along the top of the lever to the other end (an apparatus even now used in India), we do not know; but that it was some machine worked by the foot is clear; the statement being that when the Israelites had reached the Promised Land they would find it was one abounding in streams, so as to be naturally watered, and that it would not be required to be watered by the foot as in Egypt. Again, in Chronicles it is related that King Uzziah loved husbandry, and that he made many engines, unhappily not in connection with agriculture, but for warlike purposes, "to shoot arrows and great stones withal." Further, in the 7th chapter of the Book of Job, we have the comparison of the life of man passing away swifter than a weaver's shuttle; this points unmistakeably to the fact that there must in those days have been in existence a loom, capable of weaving fabrics of such widths that the shuttle required to be impelled with a speed equal to a flight from one side of the fabric to the other, and no doubt such a fabric must have

been made in a machine competent at least to raise and depress alternately the halves of the warp threads. The potter's wheel also is frequently mentioned in the Bible.

Such instances as these are sufficient to show that considerable progress must have been made in the very earliest days of history in the construction of machines whereby muscular force was conveniently applied to an end; but if we leave out of account, as we fairly may, the action of the wind in propelling a boat by sails, and the action of the wind in winnowing grain, I think we shall be right in considering that in the times of which I have been speaking there did not exist any machine in the nature of a power-giver or prime mover.

Doubtless the want of a greater force than could be obtained from the muscles of one human being must have soon made itself felt; and intelligent men, conscious of their own ability and of their mental power of directing a large amount of work, must have been grieved at finding the use of that power circumscribed by the limited force of their own bodies, and therefore early in the world's history there must have been the attempt, by the offer of some consideration or reward, to induce other men (men gifted with equal or stronger muscles, but probably not with equal minds) to work under the directions of these men of superior intelligence. But when such aid as this became insufficient, the way in which, in all probability, the people of those days endeavored to satisfy the further demand would be to make captives of their enemies and to reduce them into a state of bondage, to grind at the mill, to raise water, or, yoked by innumerable cords and beams to some heavy chariot or sledge, to draw along the huge blocks required in the foundations of a temple, or for the building of a pyramid, or to act in concert on the many oars of a galley, although by what means this last-named operation was performed is not very clear. Doubtless under this condition of things there must have been an amount of human suffering which is too frightful to be contemplated.

Such machines as those to which I have called attention could not have been invented and brought into use without the exercise of much mechanical skill; but considerable as this skill must have been it had never originated a prime mover; it had given no source of power to the world, but had left it dependent on the muscular exertions of human beings and of animals.

Great then, was the step, and a most distinct era was it in mechanical science, when for the first time a prime mover was invented and a machine was brought into existence which, utilizing some hitherto disregarded natural force, converted it into a convenient form of power, by which as great results could be obtained as were obtainable by the aggregation of a large number of human beings, and could be obtained without bondage and without affliction.

There are probably few sights more pleasing to one who has been brought up in factories than to watch a skillful workman engaged in executing a piece of work which requires absolute mastery over the tools that he uses, and demands that they should have the constant guiding of his intelligent mind. Handicraft work of such a kind borders upon the occupation of the artist, and to see such work in the course of execution is, as I have said, a source of pleasure. But when descending from this the work becomes more and more of the character of mere repetition, and when it is accomplished by the aid of implements which, from their very perfection require but little mind to direct them, and demand only the use of muscle, then, although the labor, when honestly pursued, is still honorable, and therefore to be admired, there comes over one a feeling of fear and of regret that the man is verging towards a mere implement. But when one sees, as I have seen in my time, in England, and as I have seen very recently on the Continent, men earning their living by treading within a cage to cause it to revolve and thereby to raise weights, an occupation demanding no greater exercise of intelligence than that which is sufficient to start, to stop, and to reverse the wheel at the word of command, one does indeed regret to find human beings employed in so low an occupation, an occupation that places them on a level with the turnspit. It is one which is most properly meted out in our prisons as a punishment for crime, accompanied, however, with the degradation that the

force exerted shall be entirely wasted in idly turning a fan in the free air, and thus the prisoner, in addition to the fatigue of his body, undergoes the humiliation of, as he expresses it, "grinding the wind."

If they played no other part than that of relieving humanity from such tasks as these, prime movers would be machines to be hailed.

True it is that the laborers who were thus relieved would not thank their benefactors, and indeed so far as the individuals subjected to the change were concerned they would have cause not to thank them, because they, having been taught no other mode of earning a livelihood, and finding the mode they knew set on one side by the employment of a prime mover, would be at their wit's end for a means of subsistence, and would be experiencing those miseries which are caused by a state of transition. But in some way the men of the transition state must be relieved, and in the next generation, it no longer being possible to subsist by such wholly unintelligent labor, the energies of their descendants would be devoted to gaining a livelihood by some occupation more worthy of the mind of man.

Early prime movers, from their comparatively small size, probably did little more than thus relieve humanity; but when we come to consider the prime movers of the present day, by which we are enabled to contain within a single vessel and to apply to its propulsion 8,000 indicated horse-power, or an equivalent of the labor of nearly 50,000 men working at one time, we find that the prime mover has another and most important claim upon our interest: it enables us to attain results that it would be absolutely impossible to attain by any aggregation of human or other muscular effort, however brutally indifferent we might be to the misery of those who were engaged in that effort.

Excluding from our consideration light and even electricity, as not being, up to the present time, sources of power on which we rely in practice, there remain three principal groups into which our prime movers may be arranged, viz., those which work by the agency of wind, those which work by the agency of water, and those which work by the agency of heat. But some of these great groups are capable of division, and indeed demand divison into various branches.

Water power may be due to the impact of water, as in some kinds of water-wheels, turbines, and hydraulic rams, or to water acting as a weight or pressure, as in other kinds of water-wheels, and in water-pressure engines; or to streams of water inducing currents, as in the case of the jet-pump, and of the "Trombe d'eau," or to its undulating movements, as in ocean waves. The ability of water to give out motive force may arise from falls, from the currents of rivers, from the tides, or, as has been said, from the oscillation of the waves.

Prime movers which utilize the force of the wind are few in number and in all cases act by impact.

As regards those prime movers which work by the aid of heat, we may have that heat developed by the combustion of fuel, and being so developed applied to heating water, raising steam, and working some of the numerous forms of steam-engines; or, as in the case of the Giffard injector, performing work by induced currents, by the flow of steam; or we may have the heat of fuel applied to vary the density of the air, and thus to obtain motion as by the smoke-jack; or the fuel may be employed to augment the bulk and the pressure of gases, as in the numerous caloric engines; or we may have heat and power developed in the combustion of gases, as in the forms of gas-engines; or in the combustion of explosives, as in gunpowder, dynamite, and other like materials, used not only for the purposes of artillery and of blasting, but for actuating prime movers in the ordinary sense of the word.

Again, we may have the heat of the sun applied through the agency of the expansion of gases or surfaces to the production of power, as in the sun-pumps of Solomon de Caus and of Belidor, and as in the sun-engine of Ericsson. Finally, we may have the sun's rays applied direct, as in the radiometer of Mr. Crookes.

A consideration of the foregoing heads, under which prime movers range themselves, will speedily bring us to the conclusion that the main centre of all

mechanical force on this earth is the sun. If the prime movers be urged by water, that water has attained the elevation from which it falls, and thus gives out power by reason of its having been evaporated and raised by the heat of the sun. If the power of the water be derived from the tidal influence, that influence is due to the joint action of the sun and the moon.

If the prime mover depend upon the wind for its force either directly, as in windmills, or indirectly, as in machines worked by the waves, then that wind is caused to blow by variations of temperature due to the action of the sun. If the prime mover depend upon light or upon solar heat, as in the case of the radiometer and of the sun engine, then the connection is obvious; but if the heat be due to combustion, then the fuel which supports that combustion is, after all, but the sun's rays stored up. If the fuel be, as is now sometimes the case, straw or cotton stalks, one feels that they have been the growth of the one season's effect of the sun's rays. If the fuel be wood, it is equally true that the wood is the growth of a few seasons' exercise of the sun's rays, but if it be the more potent and more general fuel, coal, then, although the fact is not an obvious one, we know that coal also is merely the stored up result of many ages exercise of solar power.

And even in the case of electrical prime movers, these depend on the slow oxidation, that is burning, of metal which has been brought into the metallic or unburnt state from the burnt condition (or that of ore) by the aid of heat generated by the combustion of fuel.

The interesting lecture-room experiment with glass tubes charged with sulphide of calcium, or other analogous sulphides, makes visible to us the fact that the sun's rays may be stored up as light; but that they are as truly stored up (although not in the form of light) in the herb, the tree, and the coal, we also now know; and we appreciate the far-seeing mind of George Stephenson who astonished his friend by announcing that a passing train was being driven by the sun. We know that Stephenson was right, and that the satirical Swift was wrong when he instanced as a type of folly the people of Laputa engaged in extracting sunbeams from cucumbers. The sunbeams were as surely in the cucumbers as they are in the sulphide of calcium tubes, but in the latter case they can be seen by the bodily eye, while in the former they demand the mind's eye of a Stephenson.

Although the sailing of ships and the winnowing of grain must, from very early time, have made it clear that the wind was capable of exercising a moving force, nevertheless, being an invisible agent, it is not one likely to strike the mind as being fit to give effect to a prime mover, and therefore it is not to be wondered at that prime movers actuated by water are those of which we first have any record, unless indeed the toy steam-engine of Hiero may be looked upon as a prime mover anterior to those urged by water. It would appear that in the reign of Augustus water-wheels were well known, for Vitruvius, writing at that time, speaks of them as common implements, but not so common as to have replaced the human turnspit, as we gather from his writings that the employment of men within a tread-wheel was still the most ordinary of obtaining a rotary force. It would seem, however, that water wheels driven by the impact of the stream upon pallet boards were employed in the time of Augustus not merely to raise water by buckets placed about the circumference of the wheels, but also to drive mill-stones for grinding wheat, and Strabo states that a mill of this kind was in use at the palace of the King of Pontus.

Having thus mentioned the earliest record of hydraulic (or indeed of any) prime movers, I will not endeavor to trace their history down to modern times, as it would be impossible to do so usefully within the limits of an address. I will therefore now ask you to join me in considering what are the conditions which govern the application of water to hydraulic prime movers.

After all water must be looked upon as a convenient form of descending weight. When the fall is not great it is always practicable by means of water-wheels having buckets which retain the water to employ, as I have said, its mere gravity, and probably it is by this mode that the highest result is procured from any given quantity of water falling

through a given height. By the use of a backshot wheel as much as seventy-five per cent. of the total power is obtainable. The twenty-five per cent. of loss arises from the friction of the axle of the wheel and of the gearing transmitting the force to the machine which is to utilize it; from some of the water being discharged out of the buckets before the bottom of the fall is reached; from the necessary clearance between the wheel and the tail water; from the eddies produced in the water, as it enters the buckets, and (to a certain small extent) from the resistance of the air.

When the difference of level between the source of water and its delivery exceeds, however, forty or fifty feet, the water-wheel becomes so unwieldy and expensive and revolves so slowly that it ceases to be a desirable prime mover; recourse can then be had to water-pressure engines, engines wherein pistons move in cylinders and being pressed alternately in opposite directions by the head of water set up rotary motion in the machine in the same way as if the pistons were acted upon by steam. In the construction of such water-engines great care must be taken to have ample inlets and outlets in order that the loss incurred either by the power requisite to drive the water through restricted orifices, or by surface resistance caused by a too speedy flow along the various passages may be a minimum. Care has to be taken also in the arrangements of the valves that the engines, when employed for rotary movement, may be able to turn their centres without producing an injurious pressure upon the water within the cylinders. Water-engines employed for pumping, but without rotary movement, are mentioned by Belidor in his "Architecture Hydraulique," published in 1739, article 1,156. In England Sir William Armstrong has brought these machines to great perfection. The first of these, erected many years ago, is still working most successfully at the Allan Head Lead Mines. This machine is driven by a natural head of water and not from an accumulator, and is employed in the mine as a winding engine.

An extremely useful feature in engines of this kind is their adaptability to be driven by the pressure of water derived from an ordinary water-works, and in this manner small manufacturers, carrying on business in their own houses, are enabled to obtain a prime mover with great ease, and, all things considered, at small cost. Not only is advantage taken of such machines for the purpose of driving manufactories, but water cylinders are now largely employed for working the bellows of church organs, for which purpose an overshot water-wheel is shown as being employed as far back as Sölomon de Caus's book, date 1615.

Large water-wheels, or even water-engines, are comparatively costly machines, and as large water-wheels make but few revolutions per minute, they require, as has been said, expensive and heavy gearing to get up speed; thus it is that it frequently becomes a desirable thing to dispense with such machines and to resort to other modes of making available high falls of water. In former times this was done by suffering the impetuous stream of water to beat upon the pallets of water-wheels, but from such machines only a poor effect could be obtained, as a large portion of the energy in the water was devoted to the formation of eddies and the generation of heat, and to the production of lateral currents, leaving but a small percentage available as motive power.

Much of the evil effect, however, attendant upon using the impact of water as a means of driving water-wheels is obviated by the construction invented by the distinguished French engineer Poncelet. For high falls, however, the implement now generally employed is the turbine, of which the well-known Barker's mill may be looked upon as the germ.

I have got before me No. 1,983, a model of Fourneyron's turbine.

This is not an apt model for my present purposes, inasmuch as it is one to be employed with a comparatively low fall of water, but even in such instances the turbine gives most excellent results, and it has the advantage over the water-wheel of being able to work with great efficiency although there may be a considerable rise in the "tail water," a rise which would materially check the action of an ordinary water-wheel. In this turbine every care has been bestowed to give a proper form to the pallets on

which the water acts so as to take up, step by step as it were, the whole of the energy residing in the stream, so that the water may pass away from the turbine in an inert condition, and so that in acting upon the vanes of the turbine, eddies may not be formed and thus energy may not be wasted.

There are probably few sights more surprising to the old-fashioned mechanic, who has been used to see water-wheels of fifty or even seventy feet diameter employed for the utilization of a high fall, than that of a turbine occupying only a few cubic feet of space but running at such a velocity as to consume the whole of the water of a considerable stream, and so to consume it as to deliver nearly as large a percentage of useful effect as would the cumbrous water-wheel itself.

If the object is merely to raise water this can be done without the employment of either water-wheel or turbine. When a small quantity is required to be raised to a considerable height the Montgolfier ram is employed. No. 1,996, which I have before me, is a glass model of such a ram, but I fear it is too small to be visible, except to those who are very near to the table. You are, however, all aware that the principle of action consists in the sudden arrestment of a column of water flowing with a velocity due to the head. The water on being arrested performs two functions, a small portion raises an outlet valve, and thereby passes into an air-vessel against a pressure competent to drive the water up to the desired height; while the main body recoils along the supply pipe; then, the escape valve having opened, the water that has recoiled, returns, a large portion passes out of the valve, and thus the velocity being fully established the escape valve shuts and causes another arrestation and a repetition of the working. This is an implement by which a large volume of water, coupled with a low fall, can be made to raise a portion of itself to a great height. But there is a converse use of water, wherein the employment of a small stream of water moving rapidly (owing to its having fallen from a considerable height) is caused to induce a current in other water and to draw it along with itself at a diminished velocity but still with a velocity competent to raise the united stream to a less height, and in this manner many swamps and marshy lands have been drained.

This employment of the induced current as a prime mover is described by Venturier in the record of his experiments made at the latter end of the eighteenth century, and within the last few years Mr. James Thomson has applied the same principal with great success in his jet pump.

The next mode I shall notice of obtaining motive power from water, is also one where it operates by an induced current; this is the "Trombe d'eau," an apparatus wherein water falling down a vertical pipe, induces a current of air to descend with it. The lower end of the vertical pipe being connected with the upper side of an inverted vessel, the bottom of the sides of which vessel is sealed by a water joint, then the water dashing upon a block placed below the mouth of the pipe, is separated from the air, so that while the water descends and escapes from under the sides of the vessel, the air rises and accumulates in the upper part from whence it can be led away to blow a forge fire. These machines are described in Belidor's work.

The utilization of the rise and fall of the tide is also fully described by Belidor, who gives drawings of channels so arranged that during both the rise and fall of the tide the wheel, notwithstanding the reversal of the currents, revolves in one and the same direction. The tide is a source of power which it is highly desirable should be utilized to a greater extent than it is; if we consider the enormous energy daily ebbing and flowing round our shores, it does seem to be a matter of great regret that this energy should be wasted, and that coal should be burnt as a substitute.

The last mode in which power may be obtained from water, to which I have to allude, is that of the employment of the waves.

Earl Dundonald, better known as Lord Cochrane, proposed by his patent of 1833 to utilize this power for propelling a vessel; this he hope to accomplished by the use of cylinders containing mercury, the oscillations of which were to cause a vacuous condition in the cylinders, and thereby give motion to an air-

pressure engine. Lately we have had produced before the Institution of Naval Architects, and also before the British Association at Bristol, the apparatus of Mr. Tower, by which the motion of the waves is to be utilized; a model constructed on this principle has driven, it is said, a boat against the wind at some two or three miles an hour.

The next kind of prime-movers in order of date to be considered, are those that are worked by the wind.

Although, undoubtedly, the propelling of a ship by sails, and even the winnowing of grain, must have long preceded the invention of a prime mover driven by water, yet the employment of the wind as a source of motive power for driving machinery, appears to be but of comparatively recent date. It is said that the knowledge of this kind of prime mover was communicated to Europe by the Crusaders on their return from the East, but it is difficult to see what foundation there is for this statement. It appears to be certain, however, that windmotors were commonly employed in France, Germany, and Holland, in the thirteenth century.

We can easily understand that in countries where water falls in quantities and rapid streams are abundant, the windmill would not, owing to its uncertainty, be resorted to; on the other hand, in inland countries and in countries like Holland, where the streams are sluggish, and where there is a large amount of land to be drained, the wind, although still uncertain, would, nevertheless, be a valuable power, and therefore would be utilized.

Prime movers to be worked by the wind appear to have been made practically in only two forms: viz., the common one, wherein a nearly horizontal axle carries four or more twisted radial sails, and that one wherein the axle is vertical and the arms project from it laterally either as radial fixed arms, as curved fixed arms, or as arms having a feathering motion similar to that of paddle-wheels. Where the arms are straight and fixed, some contrivance must be resorted to to obtain a greater pressure of wind on one side than on the other.

Bessoni, in his work "The Theory of Instruments and Machines," published at Lyons in 1582, describes a windmill with vertical spindle and curved horizontal arms, placed in a tower with a windguard, and by the drawing shows it working a chain-pump. Belidor also says in Article 852 that windmills with vertical axles were well known in Portugal and in Poland, and he describes how that they work within a tower, the upper part of which was fitted with a movable portion to act as a screen to one side of the mill.

I will not detain you by an illusion to the sailing chariot mentioned by my Uncle Toby in "Tristram Shandy," nor will I pause to describe the very modern one, that is to say, not more than about thirty years old, which was employed upon Herne Bay Pier. In fact this Exhibition gives but little encouragement to pursue the subject of prime-movers worked by wind, as I have not as yet come across in the Catalogue any apparatus illustrative of the subject.

It is to be regretted that the use of this kind of prime-mover, the windmill, is on the decline. It is a power that costs nothing; the machinery can be erected in almost any situation; and although such a motor cannot by itself be depended on, being of necessity "as uncertain as the wind," it nevertheless might be commonly employed as an auxiliary to steam-power, diminishing the load upon the engine in exact proportion as it was urged by any wind which might happen to blow.

I may say, to the credit of our American brethren, that they employ on their sailing-ships a windmill known by the sailors as "The Sailor's Friend," to pump, to work windlasses, and to do all those matters which in a steamship fall to the lot of the donkey-engine and steam winch, unless, as in a recent voyage in which all Englishmen have been so much interested, these duties were imposed upon the baby elephant.

There is one motor which may be put either into this class or into the next, where we consider the application of heat; I allude to the smoke-jack, but beyond recognizing its existence as a prime mover, and a very early one indeed (it is to be found in Zoncas' work published in 1621), attention need not be bestowed upon it.

We now come to consider those prime movers which are worked by the im-

mediate, and not by the secondary, action, of heat.

The direct rays of the sun have, for a very long time past, been suggested as a means of obtaining motive power. Solomon de Caus, in his work published in 1615, describes a fountain which is caused to operate by the heat of the sun's rays expanding the air in a box, and expelling thereby, through a delivery valve, the water from the lower part of the box. When the sun's rays have been withdrawn, the air, cooling, contracts a suction valve, opens and admits more water into the box to be again displaced on the following day. He also gives a drawing of an apparatus where the effect of the sun's rays is to be intensified by a number of lenses in a frame. Solomon de Caus proposes these machines as mere toys to work an ornamental fountain, but Belidor, by Article 827, describes and shows a sun pump consisting of a large metallic sphere, fitted with a suction pipe and valve, and a delivery pipe and valve, and occupied partly by water and partly by air; the suggestion being as in the case of Solomon de Caus, that the heat of the sun in the daytime expanding the air should drive up the water into a reservoir, while the contraction of the air in the night-time should elevate the water by the suction pipe and recharge the sphere for the next day's work. In modern times, as we know, some attempts to obtain practical motive power from the direct action of the sun have been made, and notably by Capt. Ericsson.

The temptation to endeavor to bring into practical use a machine of this character is very great. We were told by our President, in a lecture delivered by him to the British Association at Bradford, that the solar heat, if fully exercised all over the globe, supposing that globe to be entirely covered with water, would be sufficient to evaporate a layer fourteen feet deep of water per annum. Now assuming ten pounds of water evaporated from the temperature of the air into steam by the combustion of one pound of coal (a much larger result than unhappily is got in regular work), this would represent an effect obtained from the sun's rays on each acre of water equal to the combustion of 1680 tons of coals per annum, or to about 92 cwt. of coal per acre per twenty-four hours; or enough to maintain an engine of 200 gross indicated horse-power day and night all the year round. When, however, we consider the effect of the sun, not upon the surface of water but upon the earth, and deal with its power of producing heat-giving material, the result compares very unfavorably with the work done by the sun itself; and this, no doubt, arises first, from the fact that the sun is frequently obscured, and second, from the fact that a large portion of the energy of the sun is spent in evaporating moisture from the ground, and not in the direct production of combustible material. I have found it extremely difficult to obtain any reliable data as to the weight of fuel grown per acre per annum. If we take the sugar cane, we find that in extremely favorable cases as much megass and sugar together are produced as would equal in calorific effect about five tons of good Welsh coal. Coming to our own country and dealing with a field of wheat, the wheat and straw together may be taken as being equal probably to about two tons of coal as a maximum. The statements made to me with regard to the production of timber per acre per annum, when grown for the purpose of burning, are very various; but the best average I can make from them is, that in this country there is produced as much wood as is equal in calorific effect to about one and a half tons of good coal per acre. Comparing these productions of heat-giving material with the energy of the sun, as shown in the evaporation of water, one shows how tempting a field is that of the direct employment of the solar rays as a source of power; more especially, when it is remembered that those rays are obtained from week to week, and year to year, without having to wait the tardy growth of the fuel-destined tree.

I will now ask you to consider with me the prime movers that owe their energy to the heat developed by the combustion of some ordinary kind of fuel—coal or wood. Passing by, as a mere toy and not an actual prime mover, the reactionary steam sphere, the eoliopile of Hero, I will come at once to those simple forms of heat-engine (whether worked by steam or the expansion of air), by

which water was to be raised. Solomon de Caus, in his work of 1615 already mentioned, says, that if you fill a globe with water and have in its upper part a pipe dipping nearly to the bottom, and if you put the globe upon the fire the heat will cause the expansion of the contents, and the water will be delivered in a jet out of the tube.

The Marquis of Worcester in his "Century of Inventions," published in 1569, makes, as is well known, a similar proposition, but it does not appear that these machines were seriously contemplated for practical use. Papin (I take Belidor's Article No. 1,276 as my authority) in 1698 (as appears in his pamphlet of 1707) experimented by order of Charles, the Landgrave of Hessen Cassel, with the view of ascertaining how to raise water by the aid of fire. But his experiments were interrupted and he did not resume them until Leibnitz, by a letter of Jan. 6, 1705, called his attention to what Savery was doing in England, sending him a copy of a London print of a description of Savery's engine. This engine, which of course is well known to you, is illustrated by a model in this collection, and now on the table before me. Savery employed a boiler, the steam from which was admitted into a vessel furnished like the sun-pump of Belidor with a suction pipe and clack, and a delivery pipe and clack; the steam being shut off, cold water was suffered to flow over the vessel, a vacuum was made and water raised into the vessel, which was expelled out of the delivery pipe upon the next admission of steam, the cocks being worked by hand. This machine came into very considerable use and was undoubtedly the first practical working steam engine. It had, however, the defect of consuming a large quantity of steam, as the steam not only came into contact with the cold vessel but also with the surface of the water in that vessel. Papin, as we know, obviated a portion of this loss by the employment of a floating piston placed so as to keep the steam from actual contact with the surface of the water.

We have in the collection, No. 2,007, a cylinder from Hessen Cassel, said to be of the date of 1699 and to have been intended for employment in Papin's machine, but it is difficult to say for what part of the apparatus it could have been designed, inasmuch as the cylinder is provided with a flange at one end only and no means, so far as I can ascertain, exist for closing the other end. You will see from the diagram that which, no doubt, is already well known to you; Papin did not propose to condense the steam, and by its condensation to "draw up" the water (to use a familiar expression), but intended that the vessel should be charged by a supply from above, and, that the steam should be employed only to press on the floating piston and to drive the water out. Papin, however, hoped to use his engine, not merely as a water-raiser, but as a source of rotary power by allowing the water to issue from the air vessel, so as to impinge upon the pallets of a water-wheel and thus produce the required revolution.

AMERICAN IRONMAKING.

From "Iron."

RECENT reports on the condition and progress of iron and steel making in the United States are not only full of interest, but of warning to English makers. Confident in the possession of cheap labor and cheaper raw material, our home manufacturers were, in the period of their prosperity, not unnaturally somewhat slow in adopting the newest improvements. Trade was so good, and labor for a time so plentiful, that outlay on new plant seemed a work of supererogation. So much was labor and fuel-saving machinery overlooked, that within half-a-dozen years great establishments were worked with appliances of venerable antiquity. The old, wasteful and unpractical form of blast-furnace was met with in ironworks of world-wide fame, and the conviction that ancient methods of working were preferable to the introduction of novel

and costly plant prevailed very generally. In the United States the conditions of existence by the iron trade were widely different. The sickly infant required careful nursing and tending, and its growth proved costly enough to the whole body politic. Almost prohibitory duties failed to protect the juvenile industry of Pennsylvania against foreign competition. Immense imposts were laid upon European goods, with the simple result of raising prices and increasing the demands of the working population. The process of "leveling-up" went on at a tremendous rate, until it was found that the profits realized by the assimilation of the prices of home-made articles to those of foreign manufacture were almost entirely absorbed by the artisan. Then the American manufacturers of iron and hardware commenced a line of policy which was attended by remarkable success until the recent arrest of the iron trade, and promises in the future to have a severe effect upon our own commerce. All the efforts of a singularly long-headed and energetic people have been—for several years past—devoted to the object of reducing the cost of manufacture by the introduction and improvement of machinery. The success of those endeavors has been proved by the stand that American hardware has been enabled to make against our own goods in our own colonies. It would seem as if that necessity which compels the ingenuity of man to redress the inequalities of nature, which has made Scotch agriculturists and horticulturists the best in the world, had operated on singularly plastic material in America. Wherever machinery could be introduced it was pushed forward, to the ultimate supercession of hand-labor. The dream of the capitalists, despite the "highfalutin" about protecting American industry and the legitimate gains of the American artisan against the "pauper labor" of Europe, was his own emancipation from the tyranny of trades unions and the insolence of workmen's delegates. The entire bent of American ingenuity since the civil war has been to elide the hand of the cunning workman from every enterprise in which capital is involved, and the effect of this determination of human intellect in one particular direction has been to place America far before all other nations in the wholesale employment of devices for saving, or doing without, human labor. So far as the iron trade is concerned, it would be idle to suppose that our cousins have much to learn from us. American engineers and smelters travel over Europe as well as England, and are singularly well fitted to decide upon the particular process best adapted for given material and locality. Henceforward, Americans, Belgians, and other competitors for the iron market of the nations, start from the same, if not a more favorable level, than that occupied by England. The distance which separates the deposits of iron from those of coal in several parts of the United States has strongly stimulated the utilization of waste heat. In Mr. Harriss-Gastrell's report on the iron and steel industries of the United States, an interesting account may be found of the many schemes adopted from time to time for saving the heat generated by the coal for which the ironmaker is dependent upon the miner. The practice of "cogging" instead of hammering blooms, which, on its recent introduction into Sheffield, threw a large number of hammermen out of employ, was tried and employed long ago in America. So far as Bessemer steel is concerned, American makers appear almost agreed in preferring rolled or "cogged" to hammered blooms, and have devoted much time and thought to perfecting the machinery for the more modern process. It has been settled to their satisfaction, at least, that rolling produces a steel of greater uniformity in texture and greater ductility. "Rolling also saves excessive waste in rail ends, since rolled blooms being equal in section give equal weights for the same lengths; while hammered ingots vary considerably in section, requiring a maximum allowance for fag ends." Particular attention has been turned of late years to the production of Bessemer steel, and it has been proved in America, as in this country, that "in some localities Bessemer rails can be produced almost as cheaply as the best iron rails." We have, in a previous issue of *Iron*, adverted to the swift growth of the Bessemer rail trade in the United States, and to the probability that the make of steel

rails will altogether outrun that of iron, and it is needless to strengthen that conclusion by any fresh quotations. That steel will ultimately supersede iron, not only for railway material, but for boilers, boats and bridges, appears so certain that our Cleveland makers, certainly not the least clear-sighted in this or any other country, are striving desperately against the objectionable quality of their native pig-iron, and endeavoring to naturalize in the North a steel in the place of an iron rail trade. The Americans have been quicker than ourselves to apprehend the period of transition, and have gained a good start in saving labor and in improving processes and machinery. Among a people desirous of new things, a new suggestion is immediately inquired into; if it looks practical, it is tried; and, if successful, applied. The utilization of the waste heat of furnaces, the rotary squeezer, the three-high rolls, the nail, screw and horseshoe machines, and the improvements in Bessemer plant, testify abundantly to the practical manner in which the United States has striven to make up its lost ground in the iron trade; and it is noteworthy that a season of adversity has been productive of considerable improvements in our English methods of working—by precisely the same kind of pressure as that which has been in operation for many years past in America. One step—talked about for years in this country—and practised all the while in Styria, has actually been accomplished—the immediate conversion of melted raw iron into Bessemer steel without allowing it to solidify into the intermediate form of pig.

We are content to accept this step in advance as a happy augury that England will not easily be outstripped in the impending struggle for the position of chief steelmaker to the world; but we would, at the same time, point out that every year new competitors spring into the market, and that both energy and ability must be employed if England is to hold her own.

THE MECHANICAL THEORY OF HEAT.*

From "The Engineering and Mining Journal."

The history of scientific progress clearly indicates the fact that there are two processes by which our knowledge of natural phenomena is obtained. The first is experimental or observational. In it we take the facts of Nature as they are presented to us in their simple or concrete forms; we study and analyze them; we subject them to trials of various kinds, or observe them in their varying relations, and thus we seek the comprehensive law which underlies them. The second process, although often coexistent with the first, is philosophically distinct from it. When, by a wide application of the first process, the general underlying law has been detected, we formulate it, extend it to other facts not examined, and by its development arrive at the knowledge of new truth. It is only when this process has been well advanced that any branch of knowledge has a right to the name of science.

The history of the Science of Mechanics well illustrates these ideas. Although in its development the deduction went hand in hand with the deductive method, from the time of Archimedes to that of Newton, it may said to have been in the experimental or observational stage. Even Newton, superb analyst as he was, sought rather to extend the knowledge of mechanical principles and laws, than to generalize the science, and to formulate it. Passing over the labors of Euler and D'Alembert, we may say that the science made its greatest advance towards perfection when, in 1788, Lagrange formulated it in the *Mécanique Analytique*. In the history of Applied Mechanics, Newton, of course, stands pre-eminent. In the perfection and formulation of Mechan-

* The Mechanical Theory of Heat and its Applications to the Steam Engine, etc. By R. S. McCulloch, Civil Engineer and Professor of Mechanics in Washington and Lee University, Lexington, Va. New York: D. Van Nostrand. Price $3.50.

ics, as a science, the palm must be awarded to Lagrange.

Since the time of Lagrange there have been various improvements in the division and arrangement of the science, but only two generalizations of sufficient breadth and importance to be noticed here. The first is the general recognition of the almost universal applicability to problems of terrestrial mechanics, work, etc., of the theorem of *vis viva*. This step was due to Navier, Poncelet, Poisson, Coriolis, Ampére, and Bélanger. Its history is unwritten, and can only be gathered with difficulty from their *Memoirs*. The second step was the firm establishment of the principle of the conservation of energy, and its mathematical formulation as the basis of the science of energetics. This is due almost entirely to the development of the mechanical theory of heat; a theory which has been advanced, established, and formulated almost entirely within the last half century. It is interesting and instructive to observe how the processes which we have described have worked together in the development and establishment of this theory. Of course the first, or experimental, process has been the one most employed, for the theory is still too young to have been formulated, and followed out in all its applications. Still, much has been already accomplished in the second process.

Real knowledge concerning the nature of heat may be said to have originated in 1690, when Huyghens published his demonstrations of reflection and refraction, regarded as phenomena of wave-propagation. Young and Fresnel, in spite of bitter opposition from the followers of Newton, added greatly to the development and perfection of the theory; but not until the year 1798, when Count Rumford made his determination of the mechanical equivalent of heat, can the theory be regarded as standing upon a sound inductive basis. Since that time, as is well known to our readers, the experimental basis of the theory has been confirmed and perfected by Davy, Seguin, Mayer, Colding, Joule, and Hien. It remains only to notice what has been done towards the formulation of the science of thermo-dynamics; that is to say, towards the mathematical application of the laws of energy to the exact investigation of the well-known thermal phenomena. In 1807, Fourier laid the foundation for the mathematical theory of heat. A few years later came the valuable labors of Carnot, and more recently the admirable investigations of Sir William Thomson, Rankine, and Clausius, have greatly advanced the theory as a branch of exact science.

Before we can clearly indicate the position occupied by Professor McCulloch's work, with reference to the science of thermo-dynamics, we must briefly notice one other great advance that has been recently made in the science of mechanics; a step that peculiarly demands attention, because it has not yet received its proper recognition. More than twenty years ago, Professor W. H. C. Bartlett, of West Point, published in the preface to the first edition of his "Mechanics" the following paragraph:

"All physical phenomena are but the necessary results of a perpetual conflict of equal and opposing forces, and the mathematical formula expressive of the laws of this conflict must involve the whole doctrine of Mechanics. The study of Mechanics should, therefore, be made to consist simply in the discussion of this formula, and in it should be sought the explanation of all effects that arise from the action of forces."

The fundamental formula thus referred to, from which the whole of analytical mechanics, and the principles of undulatory physics, were then deduced, was no other than the simple analytical expression of the law of the conservation of energy.

Historically, it is true, the step from the theorem of *vis viva* to Bartlett's fundamental equation is very simple; but it must be regarded as a most important generalization and completion, if, as we believe, the principle of the conservation of energy is the foundation-truth of the science of mechanics. In this great, though simple, improvement, Bartlett has not only completed the work of Navier and Poncelet, but he has united in one equation what Lagrange scattered in several formulas throughout the *Mécanique Analytique*, and expressed in the most general, comprehensive, and perfect analytical form, the great law of physical forces now almost universally

admitted to be the basis of all physical science. We may not pause here to weigh Professor Bartlett's claim to distinction for this eminent service to exact science, but we believe that his book was not only the first, but is still the only treatise on analytical mechanics in which all the phenomena are presented as mere consequences of that single law.

Professor McCulloch's treatise on the Mechanical Theory of Heat may be regarded as a sequel to Bartlett's Mechanics. It is a systematic development of the science of thermo-dynamics from the fundamental equation of energy. The first chapter gives a brief but admirably clear history of the science. The next three chapters are devoted to a masterly résumé of theoretical dynamics, which will be found of the greatest service, even to those who have familiarized themselves with the subject in more extended works. The remaining chapters of the First Part are devoted to General Laws, Airs and Vapors, Internal Energy, Air Engines, and Thermal Laws. Under these various heads, the principles of the science of thermo-dynamics is developed in the most thorough and systematic manner. The second part of the work is a discussion of the applications of thermal laws. The two principle chapters treat of Steam and Other Vapors, and Steam Engines, their Defects and Improvements. Our space will not allow us to enter into details; but it will suffice to say that Professor McCulloch, in the treatment of this part of his subject, displays the same power of analysis as in the purely theoretical part. For ample confirmation of this statement, we must refer our readers to the book itself.

Such a book as this is rarely issued from the American Scientific press. Of course it is to be regarded not as a complete treatise, but as an introduction to the subject. Much of our knowledge concerning the phenomena and laws of heat is purposely omitted as forming no part of the special subject of the volume. Of such are Fourier's admirable investigations and their sequel, and all that relates to radiant heat. But the student of science will find in this book information which he cannot obtain from any other treatise in the English language. The whole work is a most admirable and beautiful example of the harmonious union of the inductive and deductive methods in the investigation and organization of scientific truth, and its publication ought to be memorable as that of the first work in which the principles of a special science have been developed directly from the fundamental law of energy. To every engineer who is not content with *rule of thumb* methods, but wishes to know his profession thoroughly, in theory as well as practice, we heartily commend this book.

THE "THUNDERER" BOILER EXPLOSION.

From "Nautical Magazine."

As the *Thunderer* was proceeding to the measured mile in Stoke's Bay, for her final contractor's trial, one of her eight large boilers exploded with terrific force. Up to the date of our going to press there are forty deaths, and forty more seriously injured, the result of the explosion. By the time this reaches our readers perhaps the papers will have announced the decision to which the coroner's jury have come as to the cause and responsibility of the disaster. Of course we have formed our own conclusions, and some of these, we believe, we may state here without at all encroaching upon the forbidden grounds of matters *sub judice*.

Between the engineering of the Navy and that of the Mercantile Marine there are in many respects wide differences. The very few days in each year on which the Navy steamers are at sea under full steam power, the greater number of engine-room hands, in proportion to the engine power and the general excellence of workmanship and material supplied to the Admiralty, contribute to a freedom from accidents and to a measure of

success which is not always due to the perfection of the floating machinery, but often is in spite of its imperfections. What has done well hitherto does not demand improvement. Admiralty practice is even copied by some owners going into the steam trade for the first time as the very best they can do. It seems as if the *Thunderer* explosion has been brought about through the safety-valves of the exploded boiler not acting, the stop-valve of that boiler having by neglect not been opened. The explosion may possibly be yet accounted for in some other way; but the very fact of this being at present a likely cause, our attention is directed to the safety-valves of the Navy and their efficiency in comparison with those of the Mercantile Marine.

It has been often explained in our pages that the Act of Parliament in reference to safety-valves, when it directs that they shall be so constructed as to be out of control of the engineer when steam is up, means only, that the engineer shall not have it in his power to control the self action of the valve. It does not mean that the valve is to be once put in order and then sealed up out of sight and placed out of the care of the engineer. In accordance with our interpretation, almost all merchant steamers have their safety valves so arranged that they can all be eased and turned round on their seats, even when steam is up, but they cannot be in any way controlled in their action. In the Navy the form of safety-valve construction adopted is one valve box for each boiler, that box containing two valves, of which only one can be lifted when under steam. The other valve is entirely shut up from the engineer, he can neither lift it nor turn it on its seat, and he cannot tell whether it is in working order or not. The lifting valve is not much better, he can only say that he can lift it by turning an one and a-half inch screw, but whether he is lifting a properly working valve or forcing an almost set-fast valve by the screw power provided for him, he cannot tell. In the merchant service, each valve spindle has a sleeve cross handle, fitted by a sliding cotter with a long cotter-hole in the spindle. The cotter is fitted in the sleeve, and is just clear of the top of the spindle cotter-hole when the valve is shut. The cotter-hole extends one inch or more below the cotter, and the hollow of the sleeve extends as much above the point of the spindle, so that the valve cannot be held down by the sleeve, although it can either be lifted or turned round on its seat by the sleeve handle at any time. The merchant service requires these facilities of arrangement, for, hurrying into port and out of port, their engineers have seldom time to overhaul the closed-up parts of the machinery, and this safety-valve arrangement is one that can be tested in a few seconds at any time, either at sea or in harbor.

In this particular the Admiralty arrangement, at only a few shilllings less expense on each valve, is equally efficient when in good order, but its state cannot be ascertained without some trouble, and only when not under steam. That no accident has occurred before this explosion of the *Thunderer* is an evidence of the excellent discipline and great care bestowed on the machinery of Her Majesty's fleet, and now that attention has been drawn to this inferiority of arrangement, if not positive defect, doubtless it will be rectified. A safety-valve ought to be an absolutely certain means of preventing any increase of pressure beyond the stipulated amount. The *Thunderer* has twin screws, with two sets of engines and two stokeholes. In each stokehole there are four boilers, each with four furnaces and one funnel for the four boilers. It is the foremost boiler on the starboard side of the aft stokehole that has exploded. The pressure to which the safety-valves were loaded is said to have been thirty pounds. The top front plate of the boiler has been blown off, and the part of the inside up-take attached to these plates has been forced back and distorted. A number of short stays from the up-take, with double nuts on the boiler front, have drawn the outer nuts bodily through the $\frac{7}{8}$ inch plate, testifying to the enormous pressure that must have been acting to produce such results.

The explosion occurred just as they were getting up steam for the runs; word had been passed down that they could go at what speed they liked, when the boiler burst. Captain Wilson, newly appointed to the *Thunderer*, was in the engine-room at the time, Mr. Humph-

reys, jun., one of the firm of the engineer contractors, was also below at the back of the port engine. Captain Wilson was saved by Mr. J. S. Weeks, one of the engineers; the captain had lost his way; all the lights had been extinguished by the first burst of the steam; he thought to lie down, thinking that would be safer, but he found the steam more suffocating as he stooped. He then stretched himself erect, and found a cooler stream of air there and then. Mr. Weeks came in contact with him just as he had taken the wrong turn, towards the stokehole instead of towards the ladder to the deck. Mr. Weeks had shut off the steam, but the main stop-valves for the engines were till then still running, and he then, as the captain states it, dived right into it, down to the stokehole, where the firemen and trimmers were being steamed to death.

When the report of the explosion was heard in Portsmouth, it was at first thought the magazine had exploded, for the report was like that of a large gun. It was, however, known that she had no powder on board, and when the steam was seen in great clouds, all knew that a boiler had burst, and immediately every necessary assistance was despatched, in all sorts of boats, to the scene of the disaster. The country are treating the victims of this sad explosion as they would the first of the wounded in a great war. It is a sad defect, but if every defect uncovered by the shock of this explosion be rectified throughout the whole of our Navy, the disaster may prove a blessing to the country.

REPORTS OF ENGINEERING SOCIETIES.

Association of Municipal and Sanitary Engineers and Surveyors.—The third annual general meeting of the members of this association was held lately at the Institute of Civil Engineers, Westminster; Mr. James Lemon, the president of the association, in the chair. Forty-one members were present, some members being absent on account of the assizes. The places represented included Warwick, Coventry, Manchester, Liverpool, Sheffield, Derby, Oxford, Shrewsbury, Leamington, Bristol, Ipswich, Hanley, and other important communities. The president's opening address glanced at various sanitary questions which had engaged, or were engaging, the attention of Parliament. The first paper on the agenda was on "Street Tramways" read by Mr. P. B. Coglan, of Sheffield. Mr. Coglan expressed an opinion that steam-power would ultimately supersede horse-power on tramways, and that a distance of ten miles an hour, under proper safeguards, would be attained. In the discussion which followed, Mr. Angell gave it as his opinion that all the purposes of street locomotion might be achieved by a superior class of omnibus. At present tramways, while they were slow, were an obstruction to traffic. Another member advocated the employment of tramways in cross-roads, at the same time deprecating their multiplication in populous cities. Papers on "Street Pavements as Adopted in Manchester," by Mr. Royle, and on "Constant Water Supply," by Mr. Greatorex, were read; and a discussion "On the Construction and Maintenance of Highways," a paper read by Mr. E. B. Clarke, was adjourned. In the evening the members dined at the Westminster Palace Hotel, under the presidency of Mr. James Lemon. In responding to the toast of "The Association of Municipal and Sanitary Engineers and Surveyors," proposed by Mr. Hemsley, the chairman dilated on the utility of this young association, which, although it numbered only 180 members, would he hoped soon receive a large accession. He advocated the association as a means of advancing sanitary science, of rendering mutual assistance, and of keeping down expenditure. At the adjourned meeting on Friday, the paper by Mr. E. B. Clarke, "On the Construction and Maintenance of Highways," underwent discussion. A leading suggestion in the paper was, that instead of having the channels at the side of the roads, it should run along the centre, by which means the present accumulation of moisture and consequent wear and tear would be avoided, at a saving, moreover, Mr. Clarke estimated, of 60 per cent. in the cost of construction of drains and channels. The remaining subjects discussed were—"The Duplicate Mode of Town Drainage," by Mr. A. Jacob; "The Leeds Sewage Works," by Mr. A. W. Morant; and "The Cost and Construction of Sewage Tanks," by Mr. T. W. Grindle.

Institution of Civil Engimeers.—The council of the Institution of Civil Engineers invite communications, of a complete and comprehensive character, on any of the subjects included in the following list, as well as on other analogous questions. For approved original communications the council will be prepared to award premiums, arising out of special funds bequeathed for that purpose.

1. On the flow of fluids, liquid and gaseous.
2. On portable apparatus for gauging the materials, and for the expeditious mixing of large quantities of Portland cement concrete.
3. On the value and strength of the different materials used for making concrete; with experiments on the proper proportions of the various ingredients, and of the water, whether salt or fresh, to produce the strongest mixture.
4. On the application of steam machinery for excavating, and the cost as compared with hand labor.
5. On stone-quarrying and stone-working machinery.
6. On the manufacture of cast and wrought

iron and of steel of various qualities; on the effect of the admixture of foreign substances; and on the experimental tests by which the quality may be ascertained.

7. On the process of forging by steam hammers and other percussive machinery, and by the hydraulic press.

8. On the effects of pressure on cast steel in the mould.

9. On the results of experience in the recent extended use of steel in mechanism and in works of construction.

10. On the alteration in the condition of metals caused by use or wear.

11. On the best mode of uniting steel and other metals employed in construction and in boiler work, and on the effect of the operations of punching, drilling, and riveting on such metals.

12. On the construction of warehouses and other buildings for storing goods, with the special view of resisting fire, and on the relative merits of brickwork, iron, and timber for that object.

13. On the construction of street tramways, the best means of adapting them for the conveyance of passengers and goods, and of preventing injury and inconvenience to other carriages traveling on the same roads.

14. On modern methods of constructing the foudations of bridges.

15. On the design, generally, of iron bridges of very large span, for railway traffic.

16. On the comparative merits of European and American wrought iron railway bridges.

17. On canal locks, inclined planes, and other modes of overcoming differences of level on canals,

18. On dock gates and caissons, including a description of the requisite external and internal arrangements, with recent practical examples.

19. On percussive and other rock drills.

20. On the appliances and methods used for tunnel-driving, rock-boring and blasting, in this country and abroad, with details of the cost and of the results attained.

21. On railway rolling stock capacity in relation to the dead weight of the vehicles.

22. On the best mode of testing iron and steel rails for railways.

23. On the water supply of towns, including a description of the sources of supply, of the different modes of storing, collecting, and filtering water, of the various incidental works, of the distribution to the consumers, and of the general practical results.

24. On the constant service of water supply, with special reference to its introduction into the metropolis, in substitution for the intermittent system

25. On the various modes of dealing with sewage, either for its disposal or its utilization.

26. A history of any fresh water channel, tidal river, or estuary,—accompanied by plans and longitudinal and cross sections of the same, at various periods, showing the alteration in its condition,—including notices of any works that may have been executed upon it, and of the effect of the works.

27. On the relative value of upland and of tidal waters in maintaining rivers, estuaries and harbors.

28. On the different systems of river and canal towage.

29. On improvements in the construction of furnaces and on combustion.

30. On the construction of steam boilers, adapted for very high pressures.

31. On the best practical use of steam in steam engines, and on the effects of the various modes of producing condensation.

32. On the results of experiments in steam jacketing.

33. On the modern construction of marine engines, having reference to economy of the working expenses, by superheating, surface condensation, high pressure, great expansion, &c.

34. On the construction of portable steam engines, or other motors, of very light weight, suitable for light boats, aerial machines, &c.; and on condensing with air.

35. On the relative cost of the conveyance of coal by rail and by steamer, and on the best mode of loading and unloading to diminish breakage.

36. On the various descriptions of pumps employed for raising water or sewage, and their relative efficiency.

37. On the employment of wind or water as a motive power, their relative advantages and disadvantages compared with steam power, and the motors most suitable for utilizing them in the best manner.

38. On the use of gas as a motor.

39. On the best methods of removing grain in bulk from a ship to a warehouse, for distributing in the warehouse, and on the various modes in which grain is stored in bulk.

40. On the manufacture of mineral oils, and the lamps best adapted for their consumption in dwellings and lighthouses.

41. On the "output" of coal in the United Kingdom, as compared with that of other countries, illustrated by statistical tables, plans, and diagrams showing where coal is produced, and where and how it is consumed.

42. On the sinking of, and machinery applied at, deep coal mines (in Saxony, for instance), with a notice of the modifications necessary in future coal mining operations suggested (or indicated) by the working of deep sinkings.

43. On the ventilation and working of railway tunnels of great length.

44. On compressed air as a motive power, particularly as applied to machinery in mines and to locomotives in tunnels, with some account of its application on the continent; and generally on the methods of transmitting force to distant points including details of the existing systems of rope trasmission.

45. On the dressing of the ores of lead, copper, zinc, and tin, by any other process than that of water, and on the smelting of such ores, with details of the results and cost by different methods.

46. On the washing of small coal, and the manufacture of coke and of artificial fuel.

47. On heavy and light wood working machinery.

48. On pneumatic telegraphs, and on pneumatic despatch tubes, designed with a view to

economical working, and to the attainment of high speeds in long lengths of pipe.

49. On recent progress in telegraphy, including a notice of the theoretical and practical data on which that progress has been based; with some account of the improvements in the construction of land and sea lines and in the working instruments.

IRON AND STEEL NOTES.

UCHATIUS STEEL.—The *Berg und Huettenmännische Zeitung* for October 8th, 1875, contains a description of the manufacture of this description of steel at the Wikmanshytte works in Sweden. According to the process of Uchatius the steel is made by melting in crucibles a mixture of cast iron, in a tolerably fine state of division, with pulverized calcined iron ore and charcoal powder. The cast iron employed at Wikamshytte is of a mottled quality, and is granulated by being allowed to flow on to a wheel which travels at a great speed in a water tank; the iron ore employed is the richest from the well-known Bispberg mines, and it is stamped and sieved fine before being used; it is of great importance that the iron ore and charcoal be intimately mixed together. The furnaces employed are the ordinary English crucible furnaces heated with coke, and about fifty pounds of steel is obtained from each crucible, which lasts usually about six heats, although much longer when hard than when soft steel is made; the furnaces themselves last four smelting days before requiring repairs. The hardest class of steel made is marked 02, and the contents of carbon in the different brands are as follows:

3 contains from		0.70 to 0.85	per centage of	carbon.	
2	"	0.85 " 0.95	"	"	
1	"	0.95 " 1.10	"	"	
03	"	1.10 " 1.20	"	"	
02	"	1.20 " 1.30	"	"	

Steel softer than No. 3 is seldom manufactured. The special uses to which the Wikmanshytte Uchatius steels are employed are as follows:—No. 02 is used almost alone for millstone picks and for razors; No. 03 and 1 for cutting tools; No. 1 is considered excellent for stamping dies, and No. 2 is used for tools used in stone work.

AMERICAN IRON EXPORTS.—In an article on the exports of the United States the *Iron Age* has the following:—In 1838 the Baldwin Locomotive works, of Philadelphia, exported three engines, their first shipment to a foreign country, and up to February 1st, 1876, they had exported in all 389 engines, valued at 5,005,964, dols. The increase in the number of engines annually sent abroad by this celebrated manufactory has been quite marked since 1869, when twelve foreign engines were built, followed in 1870 by fifteen; in 1871, by nineteen; in 1872, by forty-five; and in 1873 by ninety six. The reaction in the construction of railroads in all countries commenced in the year last named, and in 1874 the number of engines built upon foreign orders fell to fifty-eight, and in 1875 to eighteen.

An increase in foreign orders for delivery in 1876 has, however, occurred, amounting up to May 1st to forty engines. Of these fifteen were shipped in January last. Of the twenty-five yet to be shipped, one very fine first-class freight engine, named after the oldest son of the Emperor of Brazil, is on exhibition at Machinery Hall, in the International Exhibition. This is the export record of one manufactory of American locomotives; other establishments have also in later years shipped railway engines to foreign countries. The value of the total exports of locomotives in the last five years was as follows:—1871, 820,943 dols.; 1872, 774,296 dols.; 1873, 1,109 482 dols.; 1874, 1,145,669 dols.; 1875, 761,718 dols.

A majority of the locomotives in use on Canadian railways were made in America. American locomotives are in general use on most South-American railways, and on the Continent of Europe, especially in Russia, they are in high favor. The secret of the popularity abroad of these locomotives consists in the superior style of their construction, and the effect of this superiority is seen in their ability to do a greater amount of work than foreign locomotives. Mr. Fairlie, an eminent English engineer, recently remarked:—"You may take your best English locomotive with its maximum train, and the American will go before it; drawing it and its train and one-half more beside."

It is a well-known fact that European railway cars do not compare favorably with those of American manufacture in elegance, lightness, or durability. It is, therefore, not surprising that the exportation of passenger and freight cars should have become a prominent feature of American export trade. In the fiscal year 1874 we shipped to foreign countries 1083 cars, valued at 1,151,898 dols. In the fiscal year 1875 we shipped 394 cars, valued at 510, 861 dols., and in the succeeding six months, which ended with December 31st, 1875, we shipped 283 cars, valued at 323,220 dols. These cars were sent to Mexico, South America, England, Germany, Canada, Australia, the West Indies, Turkey and other countries. The Pullman palace car amazes Europeans by its completeness and elegance. Our street passenger cars are largely exported, and furnish the model for many of the street cars constructed in Europe. Street railways are themselves an American invention.

Our agricultural implements have long distanced all competition in foreign markets, and our exports thereof are steadily on the increase. In 1871 they amounted to 1,020,820 dols., in 1872 to 1,765,078 dols.; in 1873 to 2,513,982 dols.; in 1874 to 3,146,493 dols.; and in 1875 to 2,440, 802 dols. We send them to all countries, but most largely to Germany and to England.

American platform and other scales are exported in large quantities to foreign countries; so are American fire engines, stationary engines and stoves. American sewing machines are known and used in every civilized country. During the past five years the annual value of our exports of sewing machines has averaged 2,000,000 dols. American firearms are so superior in style and general excellence that they find a market in every country. All of the leading European countries are large purchasers of them. During the fiscal year 1875 England purchased American muskets, pistols,

rifles and sporting guns amounting in value to 2,419,513 dols. Our total exports of these articles in the last four c lendar years (since the close of the Franco-Prussian war, during which the demand was extraordinary) has been as follows: 1872, 1,165,424 dols; 1873, 1,548,227 dols.; 1874, 3,613,430 dols.; 1875, 5,184,576 dols.

American hardware and cutlery have been introduced into all markets, and with remarkable success. Even England, our principal competitor in the manufacture of these products, has been forced to acknowledge the superior excellence of many of our tools and "Yankee notions."

RAILWAY NOTES.

RAILWAY FEATURES OF THE CENTENNIAL EXPOSITION.—MANUFACTURE OF STEELED WHEELS.—Exhibit of metal and car wheels made under process of the Hamilton Steeled Wheel Company, under patents of W. G. Hamilton and George Whitney.—The attention of the Centennial visitor, if interested in improvements in metals, and especially when connected with railway matters, will not fail to be struck with this display. It will be found in the railway department of Machinery Hall.

It is made up of wheels which were made at the Altoona foundry by the Pennsylvania Railroad Company, of wheels which have seen service, new wheels, also wheels from Messrs. A. Whitney & Sons, of Philadelphia; wheels from the Jackson & Woodin Manufacturing Company, of Berwick, Pennsylvania; and Sunbury Car Wheel Company, of Sunbury, Pennsylvania; also cases of specimens of chills and portions of wheels and tests of the mixtures.

The improvement consists in the addition of steel and wrought iron to pig irons, in the manufacture of car wheels; the strength of the metal is increased fully one-quarter, and the anthracite and coke irons, and many grades of charcoal irons, are made available for car wheel purposes. The steel, besides increasing the strength of the metal, also giving chilling properties.

In 1872 the attention of the railway world was called to this improvement by the late J. Edgar Thomson, who, by the result of trials, made by the Pennsylvania Railroad, was convinced that a great economy would result by its development and adoption. The process has worked its way to this time, when, notwithstanding the very great depression in wheel-making business, some four hundred and thirty wheels are daily made under this process, and over four hundred thousand are in use—the Pennsylvania Railroad adopting it for its entire passenger and freight equipment, and making, at their wheel works at Altoona, one hundred and ninety wheels per day.

Every invention or improved process involves in its adoption a blow at some existing process of manufacture, and is sure to arouse the hostility of parties interested in the existing processes. This fact has been exemplified in the history of almost every important invention, and the process, controlled by the Hamilton Steeled Wheel Company, is no exception to the general rule. In fact, the introduction of such a process is attended with especial difficulties, when it is remembered that the manufacturers of the pig irons used in car wheels, as a rule, control the wheel works, as the consumers of their products.

In the exhibition of wheels we notice particularly two wheels, marked, made of coke and anthracite iron and steel, taken from under Pullman cars after making 156,800 miles; one broken to show the chill, the other still fit for service; also, other wheels from the Pennsylvania Railroad foundry, at Altoona, having made from 120,000 to 140,000 miles. A wheel made of anthracite iron and steel, broken to show its chill, and by the form of its fracture denoting great strength and fine chill. Also, one wheel, the ordinary steeled passenger wheel of the Pennsylvania Railroad, from Altoona, which has been subjected to over 450 blows of a very heavy sledge, and has eight holes knocked through the plate, the wheel, with the exception of these holes, being perfect, not cracked, or a bracket broken.

A sample of Scotch iron alone having a tensile strength of 18,786 lbs., which, by the addition of steel, has been increased to 22,327 lbs. Charcoal irons testing alone 20,008 lbs., by the addition of steel raised to 26,614 lbs. Richmond car-wheel iron testing to 22,327 lbs., raised with varying quantities of steel to 25,143 lbs., 27,640 lbs., and 29,064 lbs., the highest being 39,694 lbs.

Samples of portions of plates of wheels from Messrs. A. Whitney & Sons look more like pieces of ruptured wrought-iron plates than cast iron. A single plate wheel sixty inches in diameter, is a fine casting; and the largest wheel shown in the exhibition in the case below is a sample chill test of this wheel, showing a fine chill.

To show the wearing qualities of these wheels, the exhibitors furnish the mileage of 114 car wheels made at the Altoona foundry by the Pennsylvania Railroad Company, being all the wheels taken from under Pullman cars on that road during February last, which shows that the wheels made a total mileage of 5,973,200 miles; average, $52,336\frac{48}{100}$. Of these, thirty-one wheels are still good for service after making an average mileage of 45,579 miles; the wheels flat from sliding, an average mileage of $27,146\frac{52}{100}$; and the sixty wheels worn out by service, an average mileage of $65,564\frac{52}{100}$ miles.

This mileage is equal to that of any cast-iron wheel made, and most extraordinary when it is known that the cost of these wheels hardly exceeded ten dollars each for a wheel weighing 545 lbs. To show that the wearing qualities must be good, we give the mileage of each wheel worn out, from table of exhibitors, not having space to give the entire table in full:

MILEAGE OF WHEELS WORN OUT.

61,999	21,010	62,213	54,240	51,731
71,742	73,219	62,123	54 240	53,199
71,742	78,982	61,165	82 234	53,199
55,092	60,324	61,165	159,312	84,541
89,673	60,324	61,165	159,312	54,103
41,629	49,932	76,254	94,368	54,103
41,629	84,303	76,254	75,845	61,313
69,034	79,194	30,507	75,845	61,313

69,034	50,328	41,252	56,377	41,252
56,148	36,401	41,252	44,548	73,582
54,240	34,546	73,582	110,008	69,838
78,878	82,234	34,182	78,878	

or an average of $65{,}590\frac{12}{100}$ miles.—*Railway World.*

THE RAILROADS OF THE WORLD.—Dr. G. Stuermer, of Bromberg, Prussia, has for some years collected statistics of the length of railroads throughout the world. We summarize below his conclusions for the year 1875, in which we have made corrections for the United States and Canada:

EUROPE.

Country.	Opened in 1875.	Total at close of 1875.
Germany	1,493	17,372
Austria	467	10,792
Great Britain	250	16,699
France	573	13,414
Belgium	62	2,167
Holland	....	1,011
Luxemburg	...	166
Switzerland	283	1,293
Italy	196	4,777
Spain	169	3,602
Portugal	69	641
Denmark	130	783
Sweden	406	2,465
Norway	....	310
Russia in Europe	81	11,525
Turkey in Europe	....	955
Roumania	168	766
Greece	0	7
Total in Europe	4,347	88,745

ASIA.

Russia in Asia	304	623
Asia Minor	47	249
Hindostan	216	6,489
Ceylon	....	82
Java	....	162
Japan	....	38
Total in Asia	567	7,643

NORTH AMERICA.

Canada	*	4,830
United States	1,545	74,183
Mexico	50	377
Total	1595	79,397

Dr. Steurmer notes no additions to the mileage of any country in Central or South America, Australasia or Africa, in 1875; but there probably were some railroads constructed in South America during that year. The total mileage of each of these countries is given below:

AFRICA.

Egypt	950
Algiers	333
Tunis	37
Cape Colony	65
Mauritius	66
Total in Africa	1,451

* A large amount was constructed in 1875, but we are not able to say how much.

CENTRAL AMERICA AND WEST INDIES.

Honduras	56
Costa Rica	29
Cuba	400
Jamaica	27
Colombia (Panama Railroad)	47
	559

—*Railroad Gazette.*

ENGINEERING STRUCTURES.

MONOLITHIC AQUEDUCT. — The aqueduct from La Vanne to Paris, 135 miles long, is nearly entirely of *beton Coignet*. The Fontainebleau section of thirty-seven miles, over dry quicksand, is composed of a series of arches, some of them fifty feet high. Eight or ten bridges, of span from seventy-five to ninety feet, are also of *beton*. For foundation and gravel walls, the composition is, sand $2\frac{1}{2}$, gravel $2\frac{1}{2}$, hydraulic lime 1, Portland cement $\frac{1}{4}$. For pillars, abutments, &c., sand 4, hydraulic lime 1. The other portions, sand 4, hydraulic lime 1, Portland cement $\frac{1}{4}$ to $\frac{1}{2}$.

UNDERGROUND PUMPING-ENGINES.—At the Society of Engineers' meeting, in the Society's Hall, Westminster Chambers (Mr. V. Pendred, president, in the chair), a paper by Mr. Henry Davey, "On the Underground Pumping Machinery at the Erin Colliery, Westphalia," was read. The paper described what is probably the largest example of underground pumping-engines extant. The system, which was originated by the author, may be thus briefly described. In the mine (which is 1200 ft. deep) 920 ft. from the surface is placed a pair of compound differential pumping-engines, capable of raising 1400 gallons per minute to the surface, at the same time supplying power through the medium of the rising column to two differential hydraulic pumping-engines placed at bottom of the mine, and employed in lifting 1000 gallons per minute to the main engines. Steam is carried down to the main engines from the surface at a pressure of 70 lbs. per square inch. After passing through the engines it is condensed, and a vacuum of from 24 to 26 inches of mercury is obtained by means of a separate condenser, which produces at once a vacuum on the engine, and enables it to start to work against the full column. The methods employed for actuating the valves in the steam and hydraulic engines were also fully shown. In the latter case the valves are worked without any metallic connections by means of a modification of the differential gear.

THE MISSISSIPPI JETTIES.—THE RESULTS ACCOMPLISHED.—General Comstock, of the United States Engineers, who, under the direction of the Secretary of War, has charge of the required examinations, has made several detailed reports relating to the progress of the works and the condition of the partly-made channel through the bar. His latest published report is dated June 19, 1876, made to General A. A. Humphrey, U. S. A., Chief of Engineers, in special response to special requirements, dated April 25, 1876.

No one questions either the ability or the in-

tegrity of General Comstock in the fulfilment of this important duty. As his report shows very clearly, the works are not yet complete on any part of the length of the jetty channel, a length of nearly two and a half miles; yet their effect has been very great, and they are already useful in having opened another ship outlet, which did not before exist, and which in very little more than a year from the beginning offers as good a passage as can, during much of the time, be found at either of the larger passes, upon which the government is still at work stirring and scraping the bar deposit. The report is accompanied by two large sheets showing the latest soundings taken by his assistants, namely, from April 27 to May 12; all soundings being reduced, as stated, to the plane of average flood tide. (The usual rise of tide at the mouth is called about fourteen inches, and it occurs but once a day.)

General Comstock says on page 5 of the report: "Perhaps a clearer statement would be the following table, showing the draught of water that could be taken through each two thousand feet of the channel below East Point Station in June, 1875, and in May, 1876:

	0 to 2,000 feet.	2,000 to 4,000 ft.	4,000 to 6,000 ft.
Draught, 1875. .	22.5	18.7	16.7
Draught, 1876...	23.3	20.3	23.0
	6,000 to 8,000 ft.	8,000 to 10,000 ft.	10,000 to 12,100 ft.
Draught, 1875...	10.2	9.7	9.2
Draught, 1876...	21.0	17.1	15.7

This presentation of the effect of the jetties, even in their incomplete condition, referring as it does only to the 12th of May, shows the powerful washing-out which must have taken place thus to form a navigable ship channel within a few months from the time that the jetties were advanced far enough to actually confine the water. This scouring has not ceased, and, as already mentioned, at the last date the depth was not less than nineteen feet all the way, and, with the exception of seventy-five feet in length, it was twenty five feet deep entirely through a bar where a little more than a year ago there was less than eight feet at low tide, and only about nine feet at flood tide.

The charts accompanying this progress-report of General Comstock are very elaborate and minute. They show that an immense mass of bar material has been picked up by the concentrated current induced by the confinement of the flow between the jetties and carried gulfward. Its distribution, to a large extent, may also be traced by means of the same chart, and it shows that a large part of the sand and mud has been carried far forward, since little if any filling has occurred a short distance beyond a few hundred feet out in front, while it has shoaled decidedly on the outer sides of both jetties, thus greatly strengthening and protecting them from lateral wave-action and obviously rendering them much more secure. In regard to the effect in front, referring to the three lines of sections taken by his assistant, Captain Brown, General Comstock says that "all these sections indicate a considerable deepening at distances in front of the jetties between 2,400 and 4,000 feet."

This deepening to the extent shown was scarcely anticipated by the commission who reccommended the adoption of the jetty system at the South Pass, or by the later advisory commission of military and civil engineers who examined and made report upon the works in December last.

In regard to this General Comstock adds (page 6): "In a material so soft as the mud deposited in deep water it is difficult to say what irregular changes may arise, either from its settling or from wave-action on it in storms. But a deepening here of eight or ten feet does not in advance seem probable, and the work (sounding) will at once be repeated to detect the error or verify the results of the recent survey of this area." The outer crest of the main bar (as it was anticipated that it would during the scouring out of between two and three millions of cubic yards of material from the surface of the bar) has been filled or extended out, according to the report, about three hnndred and fifty feet. General Comstock says (page 8): "The present rate of advance, arising in part at least from scour, gives, in my judgment, no definite information as to what the ultimate rate will be, and hence does not give sufficient data to modify the opinion expressed by the board of engineers, already referred to, as to the permanence of the channel when properly jettied, and with moderate extensions of the jetties from time to time."

On page 9 the report reads as follows: "Shoals previously existing or newly formed, so protect the outside of both jetties that they are not now exposed to violent wave action, except toward their sea ends. For the protected portions the mattresses used may very probably prove to have sufficient strength when covered by stone."

ORDNANCE AND NAVAL.

GREAT GUNS.—One round with the eighty-one ton gun was fired lately, at the butts in Plumstead Marshes. The charge consisted of 260 lbs. of powder, and the result showed an increase of velocity in the projectile, with a diminution of pressure in the gun as compared with previous trials. This is the first time the gun has been fired with the enlarged powder-chamber, and, so far as can be judged at present, it would appear that the alteration which has been made is conducive to the power of the gun. Sir Joseph Whitworth's new steel gun, with hexagonal bore, is come to grief. The experiments were made at the French Government butts at Gavre, and their main object was to show that, with a heavier projectile than that used with the Woolwich thirty-five ton wrought-iron gun a higher velocity, and as a consequence a greater penetrative power, could be obtained by the new weapon. The projectile used on the occasion was about four times the length of its diameter, which, as the bore of the gun in its maximum calibre is twelve inches, would give it a measurement of about four feet. It was a shell, unfilled, and weighed no less than 1,250 lbs., or fifty lbs.

69,034	50,328	41,252	56,377	41,252
56,148	36,401	41,252	44,548	73,582
54,240	34,546	73,582	110,008	69,838
78,878	82,234	34,182	78,878	

or an average of $65{,}590\frac{19}{100}$ miles.—*Railway World.*

THE RAILROADS OF THE WORLD.—Dr. G. Stuermer, of Bromberg, Prussia, has for some years collected statistics of the length of railroads throughout the world. We summarize below his conclusions for the year 1875, in which we have made corrections for the United States and Canada :

EUROPE.

Country.	Opened in 1875.	Total at close of 1875.
Germany	1,493	17,372
Austria	467	10,792
Great Britain	250	16,699
France	573	13,414
Belgium	62	2,167
Holland	....	1,011
Luxemburg	...	166
Switzerland	283	1,293
Italy	196	4,777
Spain	169	3,602
Portugal	69	641
Denmark	130	783
Sweden	406	2,465
Norway	....	310
Russia in Europe	81	11,525
Turkey in Europe	....	955
Roumania	168	766
Greece	0	7
Total in Europe	4,347	88,745

ASIA.

Russia in Asia	304	623
Asia Minor	47	249
Hindostan	216	6,489
Ceylon	....	82
Java	....	162
Japan	....	38
Total in Asia	567	7,643

NORTH AMERICA.

Canada	*	4,830
United States	1,545	74,183
Mexico	50	377
Total	1595	79,397

Dr. Steurmer notes no additions to the mileage of any country in Central or South America, Australasia or Africa, in 1875 ; but there probably were some railroads constructed in South America during that year. The total mileage of each of these countries is given below :

AFRICA.

Egypt	950
Algiers	333
Tunis	37
Cape Colony	65
Mauritius	66
Total in Africa	1,451

* A large amount was constructed in 1875, but we are not able to say how much.

CENTRAL AMERICA AND WEST INDIES.

Honduras	56
Costa Rica	29
Cuba	400
Jamaica	27
Colombia (Panama Railroad)	47
	559

—*Railroad Gazette.*

ENGINEERING STRUCTURES.

MONOLITHIC AQUEDUCT. — The aqueduct from La Vanne to Paris, 135 miles long, is nearly entirely of *beton Coignet*. The Fontainebleau section of thirty-seven miles, over dry quicksand, is composed of a series of arches, some of them fifty feet high. Eight or ten bridges, of span from seventy-five to ninety feet, are also of *beton*. For foundation and gravel walls, the composition is, sand $2\frac{1}{2}$, gravel $2\frac{1}{2}$, hydraulic lime 1, Portland cement $\frac{1}{4}$. For pillars, abutments, &c., sand 4, hydraulic lime 1. The other portions, sand 4, hydraulic lime 1, Portland cement $\frac{1}{4}$ to $\frac{1}{3}$.

UNDERGROUND PUMPING-ENGINES.—At the Society of Engineers' meeting, in the Society's Hall, Westminster Chambers (Mr. V. Pendred, president, in the chair), a paper by Mr. Henry Davey, "On the Underground Pumping Machinery at the Erin Colliery, Westphalia," was read. The paper described what is probably the largest example of underground pumping-engines extant. The system, which was originated by the author, may be thus briefly described. In the mine (which is 1200 ft. deep) 920 ft. from the surface is placed a pair of compound differential pumping-engines, capable of raising 1400 gallons per minute to the surface, at the same time supplying power through the medium of the rising column to two differential hydraulic pumping-engines placed at bottom of the mine, and employed in lifting 1000 gallons per minute to the main engines. Steam is carried down to the main engines from the surface at a pressure of 70 lbs. per square inch. After passing through the engines it is condensed, and a vacuum of from 24 to 26 inches of mercury is obtained by means of a separate condenser, which produces at once a vacuum on the engine, and enables it to start to work against the full column. The methods employed for actuating the valves in the steam and hydraulic engines were also fully shown. In the latter case the valves are worked without any metallic connections by means of a modification of the differential gear.

THE MISSISSIPPI JETTIES.—THE RESULTS ACCOMPLISHED.—General Comstock, of the United States Engineers, who, under the direction of the Secretary of War, has charge of the required examinations, has made several detailed reports relating to the progress of the works and the condition of the partly-made channel through the bar. His latest published report is dated June 19, 1876, made to General A. A. Humphrey, U. S. A., Chief of Engineers, in special response to special requirements, dated April 25, 1876.

No one questions either the ability or the in-

tegrity of General Comstock in the fulfilment of this important duty. As his report shows very clearly, the works are not yet complete on any part of the length of the jetty channel, a length of nearly two and a half miles; yet their effect has been very great, and they are already useful in having opened another ship outlet, which did not before exist, and which in very little more than a year from the beginning offers as good a passage as can, during much of the time, be found at either of the larger passes, upon which the government is still at work stirring and scraping the bar deposit. The report is accompanied by two large sheets showing the latest soundings taken by his assistants, namely, from April 27 to May 12; all soundings being reduced, as stated, to the plane of average flood tide. (The usual rise of tide at the mouth is called about fourteen inches, and it occurs but once a day.)

General Comstock says on page 5 of the report: "Perhaps a clearer statement would be the following table, showing the draught of water that could be taken through each two thousand feet of the channel below East Point Station in June, 1875, and in May, 1876:

	0 to 2,000 feet.	2,000 to 4,000 ft.	4,000 to 6,000 ft.
Draught, 1875. .	23.5	18.7	16.7
Draught, 1876...	23.3	20.3	22.0

	6,000 to 8,000 ft.	8,000 to 10,000 ft.	10,000 to 12,100 ft.
Draught, 1875...	10.2	9.7	9.2
Draught, 1876...	21.0	17.1	15.7

This presentation of the effect of the jetties, even in their incomplete condition, referring as it does only to the 12th of May, shows the powerful washing-out which must have taken place thus to form a navigable ship channel within a few months from the time that the jetties were advanced far enough to actually confine the water. This scouring has not ceased, and, as already mentioned, at the last date the depth was not less than nineteen feet all the way, and, with the exception of seventy-five feet in length, it was twenty five feet deep entirely through a bar where a little more than a year ago there was less than eight feet at low tide, and only about nine feet at flood tide.

The charts accompanying this progress-report of General Comstock are very elaborate and minute. They show that an immense mass of bar material has been picked up by the concentrated current induced by the confinement of the flow between the jetties and carried gulfward. Its distribution, to a large extent, may also be traced by means of the same chart, and it shows that a large part of the sand and mud has been carried far forward, since little if any filling has occurred a short distance beyond a few hundred feet out in front, while it has shoaled decidedly on the outer sides of both jetties, thus greatly strengthening and protecting them from lateral wave-action and obviously rendering them much more secure. In regard to the effect in front, referring to the three lines of sections taken by his assistant, Captain Brown, General Comstock says that "all these sections indicate a considerable deepening at distances in front of the jetties between 2,400 and 4,000 feet."

This deepening to the extent shown was scarcely anticipated by the commission who reccommended the adoption of the jetty system at the South Pass, or by the later advisory commission of military and civil engineers who examined and made report upon the works in December last.

In regard to this General Comstock adds (page 6): "In a material so soft as the mud deposited in deep water it is difficult to say what irregular changes may arise, either from its settling or from wave-action on it in storms. But a deepening here of eight or ten feet does not in advance seem probable, and the work (sounding) will at once be repeated to detect the error or verify the results of the recent survey of this area." The outer crest of the main bar (as it was anticipated that it would during the scouring out of between two and three millions of cubic yards of material from the surface of the bar) has been filled or extended out, according to the report, about three hnndred and fifty feet. General Comstock says (page 8): "The present rate of advance, arising in part at least from scour, gives, in my judgment, no definite information as to what the ultimate rate will be, and hence does not give sufficient data to modify the opinion expressed by the board of engineers, already referred to, as to the permanence of the channel when properly jettied, and with moderate extensions of the jetties from time to time."

On page 9 the report reads as follows: "Shoals previously existing or newly formed, so protect the outside of both jetties that they are not now exposed to violent wave action, except toward their sea ends. For the protected portions the mattresses used may very probably prove to have sufficient strength when covered by stone."

ORDNANCE AND NAVAL.

GREAT GUNS.—One round with the eighty-one ton gun was fired lately, at the butts in Plumstead Marshes. The charge consisted of 260 lbs. of powder, and the result showed an increase of velocity in the projectile, with a diminution of pressure in the gun as compared with previous trials. This is the first time the gun has been fired with the enlarged powder-chamber, and, so far as can be judged at present, it would appear that the alteration which has been made is conducive to the power of the gun. Sir Joseph Whitworth's new steel gun, with hexagonal bore, is come to grief. The experiments were made at the French Government butts at Gavre, and their main object was to show that, with a heavier projectile than that used with the Woolwich thirty-five ton wrought-iron gun a higher velocity, and as a consequence a greater penetrative power, could be obtained by the new weapon. The projectile used on the occasion was about four times the length of its diameter, which, as the bore of the gun in its maximum calibre is twelve inches, would give it a measurement of about four feet. It was a shell, unfilled, and weighed no less than 1,250 lbs., or fifty lbs.

more than the bolt fired by the Woolwich Infant, a gun of the same weight. The mild powders which are found to produce such satisfactory results with the wrought-iron guns, were first tried, but the velocities attained were disappointing, and the old description of powders, which are more violent in their action, were then resorted to. The velocity, however, was registered as 329 meters only, or about 1,080 feet, per second, and ultimately the gun broke down under the enormous strain. The inner steel tube cracked for about three feet near the muzzle, and the metal of the powder-chamber was found to have expanded to the extent of one-twelfth of an inch. One or more of the shells broke up in the gun.

BOOK NOTICES.

REPORTS OF UNITED STATES COMMISSIONERS TO THE VIENNA EXHIBITION. Edited by R. H. THURSTON, A.M., C.E. Washington: Government Printing Office. For sale by D. Van Nostrand. Price $12.00.

These reports are contained in four large volumes, and are distributed as follows:

Vol I contains the Editor's Introduction, Foreign reports on various subjects, and the official reports on Agriculture.

Vol. II contains Science, Scientific Processes and Education.

Vol. III is devoted to Engineering.

Vol. IV contains reports on Architecture, Metallurgy and the General Index.

The editing was in able hands, and the Reports will prove valuable as reference books for libraries. In point of execution they are neither better nor worse than the average Government Reports.

TRAITE D'ELECTRICITE STATIQUE. Par M. E. MOSCART. Paris: G. Masson. For sale by D. Van Nostrand. Price $12.00.

Two royal octavo volumes, numbering together about eleven hundred pages, present an appearance at least of completeness of treatment of such a subject as Static Electricity.

Aside from the historical portion, which singularly enough is quite brief, the leading topics are Distribution of Electricity; Theory of Electric Phenomena; Electrical Instruments for Observation and Measurement; Conductive and Disruptive Discharges; Electrical Experiments; Electrical Machines; The Sources of Electricity. This last subject occupies two hundred and fifty pages.

Three hundred wood cuts illustrate the text.

QUALITATIVE CHEMICAL ANALYSIS. By SILAS H. DOUGLAS and ALBERT B. PRESCOTT. New York: D. Van Nostrand.

A new edition of this excellent work is demanded, and will shortly be forthcoming. Many additions and improvements are contemplated.

The authors are well known for their success both as instructors and as writers, and in the three years that have elapsed since the last edition of their book was published, many important methods have been devised, and many compounds have assumed a new practical importance. Of such changes these talented chemists are fully apprised, and their new work will bear fruit of such knowledge.

EXPERIMENTS ON THE STRENGTH OF CEMENT, CHIEFLY IN REFERENCE TO THE PORTLAND CEMENT USED IN THE SOUTHERN MAIN DRAINAGE WORKS. By JOHN GRANT, M. Inst. C.E. London: E. & F. N. Spon. For sale by D. Van Nostrand. Price $4.25.

In reply to some inquiries for information as to Portland cement, we cannot do better than mention that a new edition of Mr. Grant's book was published at the end of last year. Mr. Grant had excellent opportunities for investigation in connection with the main drainage works, and made that good use of them which might have been expected from his known intelligence and skill. The bulk of the book was originally read at meetings of the Institution of Civil Engineers, and reports are given of the discussions which followed.

SANITARY WORK IN THE SMALLER TOWNS AND IN VILLAGES. By CHARLES SLAGG. LONDON: Lockwood & Co., 1876. For sale by D. Van Nostrand. Price $2.50.

To those interested in sanitation this little work will be welcome. The larger towns are pretty well cared for in respect to hygiene, although many of the methods employed are open to considerable improvement. In the smaller towns and villages, where advice is not so easily obtained, and local authorities are ignorant and prejudiced, very much requires to be done. Mr. Slagg has collected a great amount of useful information, a good deal of which will be found valuable to those who, in default of action on the part of authority, may desire to set their own houses in order. The subjects treated of are, first, some of the more common forms of nuisance and their remedies; secondly, drainage; and thirdly, water supply. The last is perhaps the most important of all, as all the others are to some extent dependent upon it; and we especially notice an ingenious and practical arrangement, by which, for purposes of cleanliness, and in the absence of a more suitable supply, the rain-water collected on the roof may be stored and filtered. In connection with house drainage we observe that the importance of ventilating sewers and house-drains is properly insisted on, and plain directions given for drawing off the foul air and preventing it from entering the dwelling.

A COMPREHENSIVE TREATISE ON THE WATER SUPPLY OF CITIES AND TOWNS. By WILLIAM HUMBER, C.E. London: Crosby, Lockwood & Co. New York: D. Van Nostrand. Price $60.00.

The plan of this great work is briefly this, viz.: A general division into a *theoretical* and a *practical* or *constructive* portion. The theoretical section embraces an Introductory Historical Sketch, and separate chapters on the Chemical, Meteorological and Geological elements of the subject, together with a treatise on the Flow of Water.

The constructive portion treats, first of Water Works generally, then of their parts separately; including Wells, Reservoirs, Filter

Beds, Engines, Pumps, Conduits, Mains, and the apparatus controlling the ultimate outlet of the water.

Many water works are fully described by full page plates and numerous interspersed wood cuts. Among these are the works of Bombay, Biddeford, Glasgow, Dundee, Manchester, Canterbury, Sunderland, Rotherham and Port Glasgow.

The contents of the various chapters are as follows, viz.: Historical Sketch of Some of the Means that have been Adopted for the Supply of Water to Cities and Towns; Water and the Foreign Matter Usually Associated with it; Rainfall and Evaporation; Springs and the Water-Bearing Formations of Various Districts; Measurement and the Estimation of the Flow of Water; On the Selection of the Source of Supply; Wells; Reservoirs; Purification of Water; Pumps; Pumping Machinery; Conduits; Distribution of Water; Meters, Service-Pipes and House-Fittings; Laws and Economy of Water Works.

The text covers 378 pages of the ponderous quarto. The wood cuts number upwards of 250, and there are fifty double plates. There is no other book in the English language that can be compared with this for completeness of historical information on this subject.

A Handbook of Architectural Styles. Translated from the German of A. Rosengarten. By W. Collett-Sandars London: Chapman and Hall. For sale by D. Van Nostrand. Price $6.00

Students of architecture have, in this recently-published work, another Hand-book of Architectural Styles placed before them, possessing some degree of accuracy, with the convenience of a methodical classification. The work in question is a translation from the German of the well-known treatise of A. Rosengarten, Mr. W. Collett-Sandars being the translator; and its present English rendering has had the advantage of the revision of an English architect, Mr. T. Roger Smith, who has confined himself to the task of revising the technical language of the translation. This method has some advantages; the style and diction of the original is retained, as far as possible, by the independent translator, while the exactness of English terms conveying the meaning of the original is somewhat modified and brought within the conventional terminology of the profession. Rosengarten's work is essentially more classical than mediæval in its inspiration; but on this very account the book may gain the advantage of the change in architectural feeling which appears to be creeping over the profession. The admirable "Handbook" of Mr. Fergusson, while it serves all the purposes of the student and archæologist, is too comprehensive, and perhaps a little too discursive, for the object of a handbook suitable to the class-room, or to the younger student and general reader. The present book is more concise, and is divided into two divisions—"Ancient Architecture," embracing Indian architecture, Egyptian, West Asiatic, Chinese, and the classical styles of Greek and Roman; and "Romanesque Architecture," including not only those styles generally known as Romanesque, but the later distinct developments called by the English architect and archæologist Christian or Gothic architecture. The latter division of the subject is certainly an extension of the title "Romanesque," not warranted in our nomenclature, though the German original conveys a meaning that is nearer that term than we have been accustomed to use. The term "Romance" would probably be the one the classicist would use as expressing the sentiment and features of the later forms known generally as Gothic architecture, and although the earlier Christian architecture of the middle ages may be denominated Romanesque, as that of Southern France (the Norman elements which crept into it, and which so tinctured our own round-arched style, seem to warrant a more precise shade of meaning); we should have been content if the Pointed style had been more distinctly separated in the classification. But we take the book as we find it. In looking over the list of illustrations, we find no less than 639 are given, and these are copious, and, in some instances, well-drawn and accurate delineations; though some of the woodcuts do not appear very fresh, and others are of a class unworthy the work, and appear to be culled from inferior serials.—*Abstract from review in Building News.*

The Kinematics of Machinery: Outlines of a Theory of Machines. By F. Reuleaux. London: Macmillan & Co., 1876. For sale by D. Van Nostrand. Price $7.50.

The study of pure mechanism, a branch of kinematics, in general consists of the solution of the following problems:—Given the mode of connection of two or more points or bodies with each other, required their comparative motion, and conversely given their comparative motion to find their proper connection. Now the comparative motion of two points is determined, as laid down by Willis, when (1) the velocity ratio or the proportion which their velocities bear to each other, and (2) their directional relations, are known; the latter requiring for its complete determination (*a*) the angle between the directions compared, (*b*) the angle which the plane containing the two directions makes with a plane fixed in a space, and (*c*) the angle the intersection of the two planes makes with a fixed line on the latter plane. In "Kinematics of Machinery," the English translation by Prof. A. B. W. Kennedy of Prof. Reuleaux's "Theoretische Kinematik," the study is confined within narrower limits, causing the translator not a little difficulty, as he expresses in his preface, to translate the word kinematic, carrying as it does a more extended signification here than on the Continent. Starting with the condition that the change of position is definite at each instant, and determined by the form and connection of the fixed and moving parts, Prof. Reuleaux proceeds to investigate the directional relations of the motion, and the arrangements of the parts by which the motion is best brought about, and without any reference to the idea of velocity.

On turning to the Appendix we find a most

interesting historical collection of the definitions of a machine, one of which definitions we remark includes equally an adhesive fly-paper and the red-hot poker of the clown; that given by Reuleaux, is more concise and certainly nearer the point than most of these. "A machine is a combination of resistant bodies so arranged that by their means the mechanical forces of nature can be compelled to do work accompanied by certain determinate motions."

Thus the prevention, by the resistance of the different parts, of all motion other than that desired, as well as the conversion into useful work of as much of the energy expended as its *efficiency* permits, is the function of the machine. "Those parts of a machine transmitting the forces by which the moving points are caused to limit their motions in the definite and required manner, must be bodies of suitable resistant capacity; the moving parts themselves must belong also to similar bodies." But the determination of the suitable form and sectional area of the resistant parts, though indispensable in the construction of the machine, belongs to another part of the study of machine design, and cannot be included in the kinematic discussion.

The following is the outline of Prof. Reuleaux's Classification of Constructive Elements:

Rigid Elements:
- Joints (for forming links) such as rivets, keys, keyed joints.
- Elements in pairs or in links, such as shafts and axles, levers, cranks, &c.

Flectional Elements:
- Tension organs by themselves and used with chain-closure, such as belts, cords.
- Partners of pressure organs such as pistons and plunges, steam cylinders and pump barrels.
- Springs.

Trains:
- Click-gear.
- Brakes.
- Movable couplings and clutches.

The cuts illustrating the book, are much superior to those generally to be found in theoretical books on machinery, but they do not, of course, equal the elaborate working drawings to be found in certain books on machine design. In Fig. 169, p. 218, the rope appears to have somewhat lost its way. The translator has done his work most admirably, and great must have been the ingenuity required to manufacture some of the names here presented for the first time to the English reader. In fact we could hardly imagine a book more difficult to translate, on account of the great number of specially-constructed words in it, nor do we remember having read one in which the duties of the translator have been more successfully carried out.—*Abstract of Review in Nature.*

MISCELLANEOUS.

SALT WOOD.—It is a curious fact, that in the salt-mines of Poland and Hungary the galleries are supported by wooden pillars, which are found to last unimpaired for ages, in consequence of being impregnated with the salt, while pillars of brick and stone, used for the same purpose, crumble away in a short time by the decay of their mortar. It is also found that wooden piles driven into the mud of salt flats and marshes last for an unlimited time, and are used for the foundation of brick and stone edifices; and the practice of docking timber by immersing it for some time in sea-water, after it has been seasoned, is generally admitted to be promotive of its durability. There are some experiments which appear to show that, even after the dry-rot has commenced, immersion in salt water effectually checks its progress, and preserves the remainder of the timber.

BOILER EXPLOSIONS.—The following statement issued by the Manchester Steam Users' Association is worthy of most careful attention:

Steam Boiler Explosions and the Necessity for Governmental Interference in the Interest of the Public Safety.

Return of the Number of Steam Boiler Explosions from the year 1865 *to* 1874 *inclusive, with the Number of Persons Killed and Injured thereby.*

Year.	Number of Explosions.	Persons Killed.	Persons Injured.	Total.
1865]	48	46	79	125
1866	72	87	109	196
1867	36	60	67	127
1868	45	57	60	117
1869	58	86	126	212
1870	51	78	106	184
1871	51	50	107	157
1872	51	32	113	145
1873	64	53	84	137
1874	58	68	146	214
Total for 10 years....	534	617	997	1614
Average for each year	53	62	99	161

During the past year of 1875 there were 45 explosions, killing 67 persons, and injuring 96 others. This may be compared with the average number of explosions during the last ten years as follows:

Average from the year 1865 *to* 1874 *inclusive.*

53 explosions, 62 persons killed, and 99 injured.

Returns for 1875.

45 explosions, 67 persons killed, and 96 injured

Thus the year 1875, though below the average as regards the number of explosions, was above it as regards the number of persons killed. No abatement in the sacrificeof life appears to be taking place, and this sacrifice of life recurs with such regularity year after year that there is every reason to fear that another 60 or 70 persons will be killed before the end of the present year by steam boiler explosions unless some Governmental pressure is exerted to arouse steam users to a due sense of their responsibility.